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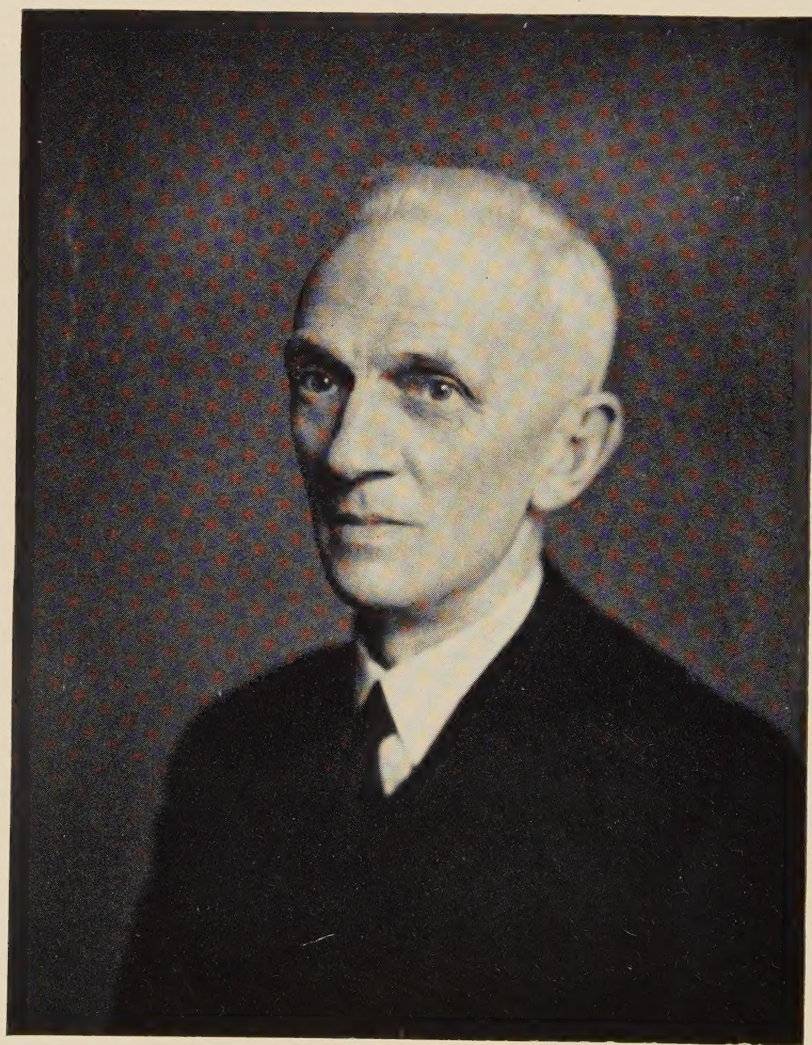
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SIR GODFREY THOMSON

SIR GODFREY THOMSON

Readers will be grieved to learn that Sir Godfrey Thomson, for many years one of the editors of this *Journal*, died in hospital on February 9th. He had long been regarded as 'the most eminent living representative of Scottish education'. Though not himself a Scot, he was born at Carlisle, not far from the Scottish border, on 27 March 1881. For the earlier part of his life his home was on Tyneside. But in 1925 he crossed the border, and the remainder of his years were spent in Edinburgh.

In his autobiography he relates how he 'went to the local Board School, and won a scholarship which provided books and free tuition at Rutherford College in Newcastle-on-Tyne'. At the age of sixteen he returned to his old school as a pupil teacher 'with a salary of £15 for the first year'.¹ Two years later he won a 'Queen's scholarship' which gave pupil teachers free tuition for a degree; and chose the Durham College of Science. In 1903 he obtained the B.Sc. with distinction in Physics and Mathematics. He then took a post as physics master in a Roman Catholic School, but shortly afterwards obtained another scholarship which enabled him to study in Germany. At that time he believed that his own future lay in the field of wireless telegraphy. He therefore decided to go to Strasburg, where the foremost German expert in the subject, Ferdinand Braun, held the Chair of Physics. In 1906 he received the doctorate *summa cum laude* for a thesis *Über den Durchgang Hertzscher Wellen durch Gitter*.

The conditions attached to the Queen's scholarship required holders, after due qualification, to teach for nine years 'in an Elementary School, the Army, the Navy, or the Workhouse'. Accordingly Thomson returned to Armstrong College at Newcastle to take up a post as lecturer to students intending to teach in elementary schools, which was accepted as equivalent to teaching there oneself. Among other courses he now had to deliver lectures on educational psychology. For this he determined to equip himself by spending the summer vacation under C. S. Myers in the Psychological Laboratory at Cambridge, where I myself first had the pleasure of meeting him. He relates how Myers 'one day brought me William Brown's little book, *The Essentials of Mental Measurement*' (to which Thomson himself later contributed several chapters), and how it aroused his interest in psychological methods. As a result he and his wife spent several months collecting data on weight-discrimination; and in 1912 he submitted the results to the Editor of the *British Journal of Psychology*. The manuscript, he tells us, was first returned with a criticism from the referee, saying 'the writer does not seem to know of F. M. Urban's work'. However, with warm encouragement from Myers, who had already decided that "the young man from the North was one of his ablest students", he set himself to study, and eventually to correct Urban's formula, "thus placing the 'constant process' on a basis which made it the precursor of the modern 'probit method'".

He next turned his attention to the second part of Brown's book. From 1904 onwards, under the influence of McDougall at Oxford, Brown, Spearman, and I had been trying to apply Pearson's new method of correlation to measurements obtained from mental tests; but as Brown reports, our conclusions were widely different: whereas I found both general and group factors, Spearman found only a general factor, and Brown found nothing but group factors. Spearman replied to Brown's criticisms in a long paper, written jointly with Hart, in which, as Thomson puts it, he made "sweeping claims for the theory that all correlations between psychological tests were due to only one factor, g ". Thomson had the happy idea of representing the rival hypotheses by patterns of dice, and was thus able to show that "it was possible to make a set of artificial test scores, without any general factor, which nevertheless gave correlations fully satisfying Spearman's criterion for the Two-Factor theory". The account was published in 1916, and formed the first of a long series of highly original papers on factorial techniques. In his own opinion his most important discovery was his

¹ *A History of Psychology in Autobiography*, Vol. IV (H. S. Langfield, ed., 1952).

proof that "the random interplay of a large number of small independent influences will produce a matrix of correlations which can be reduced to a low rank, or even to a rank of unity"; and on this he based his celebrated 'sampling theory'.

After the first world war was over, Pearson offered him a post in the Galton Laboratory at University College; but having been already assured of a Chair of Education at Newcastle, Thomson eventually decided—to the great disappointment of those of us who were working in London—to decline the offer. During the next six years he was mainly occupied in preparing his books on *Instinct, Intelligence and Character* and *A Modern Philosophy of Education*—both based on his courses as Professor of Education.

Meanwhile, Dr. Andrew Messer, the Chairman of the Education Committee for Northumberland (the county whose capital is Newcastle), persuaded the local authority to introduce a scheme of mental testing similar to that already established in London. Thomson was invited to assist in the project, and thus began the series of 'Northumberland Tests', in which I was occasionally asked to co-operate. In this way I myself became a frequent visitor to his house; and like all who came into touch with him, profited greatly from his keen and stimulating discussions of educational and statistical problems. There are few to whom I owe so much.

In 1925 he was invited to accept the Directorship of the Teacher Training College at Moray House—a post which carried with it the Chair of Education at Edinburgh. Aided by a devoted succession of research-students he continued the compilation of mental tests, now re-named 'Moray House Tests'; and generously handed over all profits to a trust, which was later able to endow a lectureship in experimental education. In his new post, he tells us, his interest in mathematical techniques was revived 'by the presence in Edinburgh University of Edmund Whittaker and A. C. Aitken, who were making fundamental contributions to this subject'—particularly in the field of matrix algebra. And later, a Sabbatical year, together with a grant from the Carnegie Corporation, enabled him to spend twelve months writing his best-known work, *The Factorial Analysis of Human Ability*. In this country it is still by far the most widely studied textbook on the subject.

Throughout this period he gave active help to the Scottish Council for Research in Education. In 1932, under the chairmanship of the Ayrshire Director of Education, the Council organized a mental survey somewhat on the lines of those carried out by Lewis and others in England, but covering a complete age-group; and in 1947, under the chairmanship of Thomson, the survey was repeated on still more ambitious and fruitful lines. The planning of the scheme and the supervision of the subsequent reports occupied most of his leisure time in the years that followed.

During the first half of the century, Britain was fortunate in having a number of scientists, many of international repute, who were interested in the application of statistical methods to psychological problems—some were statisticians, like Pearson, Yule, W. F. Sheppard, and M. S. Bartlett, others psychologists or educationists like Spearman, Nunn, Brown, Maxwell Garnett, and Thomson himself—most of them, alas, no longer with us. Nearly all were members of the British Psychological Society, and were able, just before the second war, to persuade the Council to consider publishing a new periodical dealing specifically with mathematical techniques. The war itself deferred its appearance. But in 1947 publication was started with Thomson as one of the editors. Until his health compelled him to relinquish the work, he proved an invaluable collaborator, severe in the standards which he set before us, tireless in helping junior authors, active in seeking publications from overseas. He himself contributed several papers to the earlier volumes, each a model of terse and lucid presentation. On retiring from his Chair, he planned once again to take up the statistical problems that had so often engaged his attention. His brilliant little book on *The Geometry of Mental Measurement*, published only last year, is an outline of what he had in view. We hope in a later issue to print a fuller review of his many lasting contributions to the field of education and psychology. Here it is only possible to express the grief which teachers, psychologists, educationists, and a large company of personal friends both in this country and abroad will feel at his irreparable loss.

CYRIL BURT

A STUDY OF THE PERFORMANCE OF 2,000 CHILDREN ON FOUR VOCABULARY TESTS

I. GROWTH CURVES AND SEX DIFFERENCES

By M. I. DUNSDON and J. A. FRASER ROBERTS

Burden Mental Research Department, Stoke Park Hospital, Bristol

I. Introduction: Material and Methods. II. Results: (a) Basic Data; (b) Linearity of the Growth Curves: Increment of Words with CA; (c) Equations Relating CA and Words Defined; (d) Sex Differences; (e) Intercorrelations of the Four Vocabularies; (f) Comparison with the Previous Sample. III. The Inclusion of Independent and Private Schools. IV. Absentees. V. Summary.

I. INTRODUCTION: MATERIAL AND METHODS

In a previous paper (Dunsdon and Roberts, 1953) reasons were given why it was desired to use vocabulary scales as quickly-given individual tests, not for the assessment of single children, but for the comparison of groups. For the comparison of large groups vocabulary tests have manifest advantages in respect of reliability, validity, relative absence of practice effect, and, above all, in the amount of information obtained per unit of testing time. In order to study in some detail the performance of children on vocabulary tests, and to establish norms for comparison, it was decided to apply four scales to a relatively large sample, which it was also hoped would be effectively random. By using four vocabularies the consistency of the results can be assessed, alternatives are made available, or, on the other hand, two or more vocabularies can be combined.

The four oral definition vocabularies used were respectively that of the Terman Merrill (1937 Revision) Form L, Raven's Mill Hill Vocabulary Tests A and B, and that from Wechsler's Intelligence Scale for Children. We are greatly indebted to Professor L. M. Terman, Mr. J. C. Raven and Dr. D. Wechsler for permission to use their vocabularies for this piece of work. In the subsequent text, the four vocabularies will be referred to as TML, MHA, MHB and WISC.

Mention should be made of the way in which the vocabularies were administered and scored. In the case of TML and WISC the usual procedures were employed; but, after the usually accepted limit of 5 successive failures, further words were read to the child, who was instructed to nod or otherwise indicate if he thought he could attempt a definition. The necessity for such a modification of testing procedure was referred to by Kennedy-Fraser in the report on the use of the Terman-Merrill Intelligence Scale in Scotland (1945). With Mill Hill A and B, both tests were given in the oral definition form only, and selection of synonyms was not used. As regards the limiting point, the same procedure was employed as with TML and WISC.

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For all four vocabularies the scoring was 1 point for each word satisfactorily defined. With the WISC vocabulary this involved a modification of the usual procedure, in which half points may be credited for relatively poorer definitions. The bulk of the testing was carried out by one of us (M. I. D.), the remainder by Miss M. E. Drabble and Mr. J. Annett.

The plan was to visit all the schools in the City of Bristol, together with some others outside the city boundary at which it was expected that Bristol children might be found. The children tested were those between the ages (in completed months) of 5 years 0 months and 14 years 11 months inclusive, whose birthdays fell on the first day of any calendar month. This provides a sample of approximately 3 per cent. Children whose homes lay outside the boundaries of the city were excluded. It was necessary to limit the survey to the ages at which school attendance is compulsory, for outside these limits it is practically impossible to avoid incomplete and almost inevitably biased samples.

It was found during the course of the Scottish Survey (Scottish Council for Research in Education, 1953) that sampling by day of birth in the month is highly efficient for obtaining a random sample. There was no significant difference between the total sample and the subsample in regard to 5 variables. One important advantage of this method of sampling over sampling by date of birth, appears when the testing occupies a considerable period, in this instance nearly two years. If sampling is by date of birth, the children are growing throughout the period of testing; the number of schools is finite, hence considerable bias may be introduced by the order in which they are visited.

It was found that 10 per cent. of the boys and 7 per cent. of the girls were at private and independent schools; and it is shown later in this paper how greatly the results would have been affected had these children been omitted. Another possible source of bias is failure to include absentees. Accordingly further visits were made to trace and test children who had been absent when the school was first visited. Some data on the effect of this are also given later.

Thanks to the generous co-operation of the authorities concerned and of the Headteachers, every school in the administrative area was visited, including those of the Education Authority and the independent and private schools. It is perhaps possible that one or two very small private schools may have been overlooked, though we do not think so. The small proportion of mentally defective children and children excluded from school was also included. Inevitably there must be some loss of children attending schools outside the boundaries of the city. This was minimized as far as possible by searching for Bristol children at Education Authority schools outside the area, as well as at a number of independent schools, both residential and non-residential.

The method of sampling is flexible. The limits of age and the place of residence are fixed in relation to the date on which the school is visited. During the period of testing children are moving into and out of the city. They are increasing in age, so that CA depends upon the date of the visit; children are also entering and leaving the age-span of the survey. All this is automatically allowed for, the sample representing the average for the city over a period of time and not at a given moment. The pupils are represented in proportion to their numbers in the population; and the unequal numbers at different ages seen in Table I clearly reflect fluctuations in the birthrate between 1938 and 1949.

There are two difficulties, however. The first is that children do not always start school immediately after their fifth birthday; hence the youngest age-group, 5.0 to 5.5, is not completely represented. Perhaps we should have omitted this age-group. We were anxious, however, to establish norms down to 5 years, and we

TABLE I. BASIC DATA

A. Numbers: Boys, 980; Girls, 967

B. Sums: CA (in months) and Words

	Boys	Girls
CA . . .	112,550	110,996
TML . . .	11,747	10,791
MHA . . .	10,451	9,743
MHB . . .	10,115	9,249
WISC . . .	15,638	14,255

C. Sums of Squares and Cross Products: CA (in months) and Words¹

Boys	CA	TML	MHA	MHB	WISC
CA . . .	14,031,414	1,500,497	1,345,985	1,309,351	1,928,554
TML . . .		175,675	155,567	152,242	215,952
MHA . . .			141,513	137,042	193,401
MHB . . .				135,555	188,674
WISC . . .					276,614

Girls	CA	TML	MHA	MHB	WISC
CA . . .	13,865,678	1,381,831	1,265,106	1,208,350	1,762,325
TML . . .		149,073	134,603	129,733	182,482
MHA . . .			125,531	119,549	166,915
MHB . . .				116,769	160,138
WISC . . .					232,961

¹ Corresponding figures for combinations of more than one vocabulary can be obtained algebraically.

D. Sums of Words by 6 month Groups of CA

CA		Boys					Girls				
Yr.	Mth.	NO.	TML	MHA	MHB	WISC	NO.	TML	MHA	MHB	WISC
5	0- 5	43	233	154	138	396	38	179	118	101	308
	6-11	55	319	236	204	541	80	454	285	242	733
6	0- 5	54	402	296	283	627	58	360	255	250	578
	6-11	69	481	386	374	783	56	393	321	298	621
7	0- 5	50	395	326	313	623	61	458	369	344	690
	6-11	62	522	476	457	794	51	394	358	327	603
8	0- 5	61	551	495	486	830	49	440	395	391	649
	6-11	60	663	618	578	954	41	402	371	350	575
9	0- 5	57	621	581	544	895	53	532	543	503	802
	6-11	49	568	554	520	808	57	609	608	548	865
10	0- 5	55	758	690	673	989	55	687	658	609	915
	6-11	49	668	630	618	900	49	651	625	588	831
11	0- 5	40	525	497	468	684	44	567	560	512	755
	6-11	39	613	558	535	753	33	494	470	447	595
12	0- 5	37	617	570	571	743	44	677	596	592	802
	6-11	37	640	573	555	741	42	721	666	642	823
13	0- 5	43	780	684	696	908	44	731	682	669	844
	6-11	37	745	647	632	814	31	521	475	468	598
14	0- 5	43	819	719	719	940	38	709	639	631	779
	6-11	40	827	761	751	915	43	812	749	737	889

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trust that no appreciable bias has been introduced. The second difficulty is more serious. This is the question of absentees on the day of the visit. The absentees falling within the sample were duly recorded and visits were made later—a troublesome and time-consuming task from the practical point of view; with some persistent absentees as many as six or seven visits were required. There is also the question of bias being introduced by the loss of absentees. Actually, despite assiduous pursuit, 27 boys and 45 girls in the older age-groups left school before they could be tested. At the other end of the range, absentees just over 5 years were tested when they had grown rather older, and, of course, were not replaced by corresponding children who were less than 5 at the time of the original visit. We trust, however, that these losses have not had an appreciable effect. In fact, as is shown later, in our sample the difference in performance between absentees and the remainder has proved surprisingly small.

Even though, however, the loss of some absentees (a loss which is not independent of CA) may not have made any appreciable difference to the final results, an improvement in experimental design seems called for should a future survey be planned on the same lines. It might be possible, during the original visits to schools, to define samples composed of children present that day, but absent on some previous date or dates arbitrarily selected. In this way a sample of absentees could be built up and the main sample supplemented by appropriate addition of figures from the absentee sample. If it proved practicable, this plan would ensure completeness, as well as save a great deal of time.

There is one other small loss. Twenty children, whose names were on school registers, could not be traced. They were drawn, in the main, from families apt to make sudden and spasmodic departures from the area, without notifying the school authorities of their removal or their return.

To sum up, the losses were relatively small in relation to the size of the sample; and, furthermore, while it cannot be said that they are unbiased, it may be hoped, for the reasons given, that there has been no appreciable effect on the results set out in this paper, and that the 2,000 children do represent a nearly random sample of the schoolchildren of a large city.

This paper deals with the first analysis; the question of norms and a more detailed examination of the scores will follow later.

II. RESULTS

(a) *Basic Data.* Basic data for the complete samples of boys and girls respectively are given in Table I. The figures given are those required for the analyses made in this paper. The actual bivariate frequency distributions will be more appropriately included, to the extent that space allows, in the second paper of this series, which will deal with the establishment of norms.

(b) *The Linearity of the Growth Curves: Increment of Words with CA.* It is shown in the next section that there are substantial differences in performance between boys and girls, hence they are treated separately here. For the present purpose 6-month groups of CA are used, as shown in Table I D. The fitting is shown in Table II.

It turns out that with TML and MHB there is no significant departure from linearity of increment of mean score in either sex. This is also true of MHA, though for boys only. With girls the departure from linearity in MHA somewhat exceeds the 1 per cent. level of significance. With WISC, the growth curve is significantly non-linear for both sexes, the variance ratios almost attaining the 1 per cent. point.

The main feature of the departure from linearity with WISC, as will be seen from Fig. 1, is a tendency for the rate of increment to fall off with advancing CA. In view of the similarity of the results in boys and girls, it may indeed be that this is a feature of the WISC; and in establishing norms for this vocabulary it may prove inadvisable to rely on the linear regressions. The result for MHA in girls is puzzling. There is certainly no obvious reason why the sexes should differ in this respect; and in spite of the high significance of the departure, we are rather inclined to think that it may perhaps be due to chance. It should also be noted that when MHA and MHB are used with oral definition, they are intended to be combined into a single test: a point we shall not overlook at a later stage when considering norms. It is, however, striking that, when all four vocabularies are added together, the departures from linearity are much below the 5 per cent. level of significance. Had there been a general tendency towards the same kind of curvilinearity, although non-significant in some vocabularies, it should nevertheless have been revealed when they were combined. In oral definition tests, therefore, it seems unlikely that curvilinearity is a characteristic feature of increment with age.

When vocabulary tests were first introduced, they were intended to estimate total vocabulary, the choice of words being made, for example, at random from a dictionary. It would be interesting to find, if indeed it is true, that increase in total vocabulary is, on the average, a linear function of age.

(c) *Equations Relating CA and Words Defined.* From this point onwards we have used single months as units of CA. The equations derived from the data of Table I are as follows:

TML	Boys	$y = - 3.742 + 0.136956x,$
"	Girls	$y = - 3.450 + 0.127273x,$
MHA	Boys	$y = - 4.476 + 0.131826x,$
"	Girls	$y = - 4.897 + 0.130445x,$
MHB	Boys	$y = - 5.021 + 0.133595x,$
"	Girls	$y = - 5.403 + 0.130398x,$
WISC	Boys	$y = + 2.183 + 0.119937x,$
"	Girls	$y = + 1.879 + 0.112059x,$
Combined vocabularies	Boys	$y = - 11.057 + 0.522314x,$
"	Girls	$y = - 11.871 + 0.500174x,$

where y is number of words and x is CA in completed months.

(d) *Sex Differences.* Sex differences appear consistently in the results from all four vocabularies. These are illustrated in Figs. 1 and 2, which show the observed means for complete years of CA, together with the fitted linear regressions.

The difference in mean CA between boys and girls is very small, in fact only .06 months. The regressions obtained by taking single months of CA as in the preceding section, have nevertheless been used to adjust the means of both sexes to age 114.8 months. The comparison is shown in Table III. It will be seen that the means at fixed age for boys exceed those for girls in all four vocabularies. The differences, ranging from 0.6 to 1.2 words at about $9\frac{1}{2}$ years, may not appear very large in terms of absolute words; nevertheless all are very highly significant.

Turning to the regressions, the differences, as shown in Table IV, are much smaller. Boys show a more rapid rate of growth with all four vocabularies; but with all except TML the difference is not significant: with TML it just attains the 5 per cent. level. The difference in total increment is non-significant with each of the four vocabularies. Thus, the performance of boys exceeds that of girls at all

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**TABLE IIA. TESTS FOR LINEARITY OF INCREMENT OF SCORE WITH CA
(6 MONTH GROUPS OF CA)**

Variation of Vocabulary Score	Degrees of Freedom	Sum of Squares (words) ²	Mean Square (words) ²	Variance Ratio	Significance of Deviation
TML Boys					
Linear regression . . .	1	20,710·3			
Deviations from L.R. . .	18	393·4	21·86	1·52	—
Within arrays . . .	960	13,763·1	14·34		
Total . . .	979	34,866·8			
TML Girls					
Linear regression . . .	1	18,184·8			
Deviations from L.R. . .	18	218·1	12·12	1·12	—
Within arrays . . .	947	10,250·6	10·82		
Total . . .	966	28,653·5			
MHA Boys					
Linear regression . . .	1	19,213·4			
Deviations from L.R. . .	18	272·7	16·26	1·48	—
Within arrays . . .	960	10,554·4	10·99		
Total . . .	979	30,060·5			
MHA Girls					
Linear regression . . .	1	19,136·5			
Deviations from L.R. . .	18	316·1	17·56	2·10	± +
Within arrays . . .	947	7,912·9	8·36		
Total . . .	966	27,365·5			
MHB Boys					
Linear regression . . .	1	19,693·2			
Deviations from L.R. . .	18	257·8	14·32	1·23	—
Within arrays . . .	960	11,202·7	11·67		
Total . . .	979	31,153·7			
MHB Girls					
Linear regression . . .	1	19,134·6			
Deviations from L.R. . .	18	190·0	10·56	1·11	—
Within arrays . . .	947	8,981·1	9·48		
Total . . .	966	28,305·7			
WISC Boys					
Linear regression . . .	1	15,858·3			
Deviations from L.R. . .	18	378·6	21·03	1·86	+
Within arrays . . .	960	10,839·3	11·29		
Total . . .	979	27,076·2			
WISC Girls					
Linear regression . . .	1	14,086·3			
Deviations from L.R. . .	18	3,08·1	17·12	1·92	+
Within arrays . . .	947	8,427·0	8·90		
Total . . .	966	22,821·4			

TABLE IIB. TESTS FOR LINEARITY OF INCREMENT OF SCORE WITH CA
(6 MONTH GROUPS OF CA): TOTALS FOR BOYS AND GIRLS

Variation of Vocabulary Score	Degrees of Freedom	Sum of Squares (words) ²	Mean Square (words) ²	Variance Ratio	Significance of Deviation
TOTAL. All Vocabularies. Boys.					
Linear regression . . .	1	301,166		1.33	—
Deviations from L.R. . .	18	4,089	227.2		
Within arrays . . .	960	163,635	170.5		
Total . . .	979	468,890			
TOTAL. All Vocabularies. Girls.					
Linear regression . . .	1	281,111		1.20	—
Deviations from L.R. . .	18	2,779	154.4		
Within arrays . . .	947	121,756	128.6		
Total . . .	966	405,646			

the ages studied; the difference, however, does not widen greatly with advancing CA.

It seems clear, therefore, that tests involving oral definition as such definitely favour boys; it is not merely a question of a particular vocabulary being sex-biased.

TABLE III. MEAN NUMBER OF WORDS DEFINED AT FIXED CA
(114.8 MONTHS)

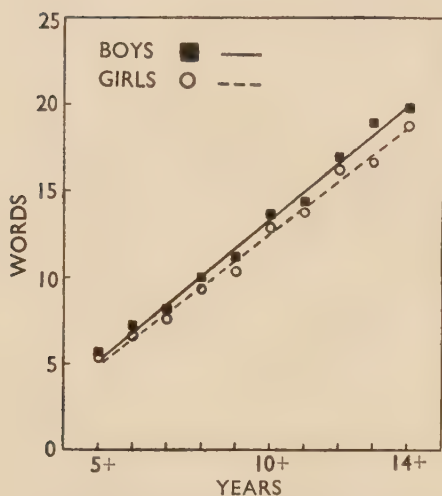
Vocabulary	Boys	Girls	Difference Boys — Girls	S.E. of Diff.	Diff./S.E.
TML	11.980	11.161	+ 0.819	0.1610	5.09
MHA	10.658	10.078	+ 0.580	0.1419	4.09
MHB	10.315	9.567	+ 0.748	0.1475	5.07
WISC	15.952	14.743	+ 1.208	0.1448	8.34
Total . . .	48.905	45.549	+ 3.356	0.5547	6.05

TABLE IV. INCREMENT IN WORDS PER YEAR OF CA

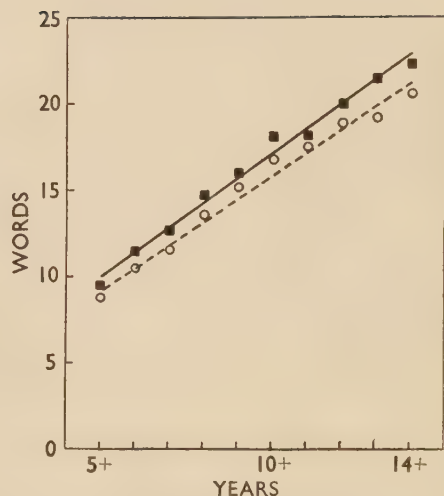
Vocabulary	Boys	Girls	Difference Boys — Girls	S.E. of Diff.	Diff./S.E.
TML	1.643	1.527	+ 0.116	0.0571	2.03
MHA	1.582	1.565	+ 0.017	0.0504	0.34
MHB	1.603	1.565	+ 0.038	0.0523	0.73
WISC	1.439	1.345	+ 0.094	0.0514	1.83
Total . . .	6.267	6.002	+ 0.265	0.1969	1.35

A personal communication from Mr. Raven is very pertinent at this point. He tells us that, in making up MHA and MHB, he was careful to reject any words

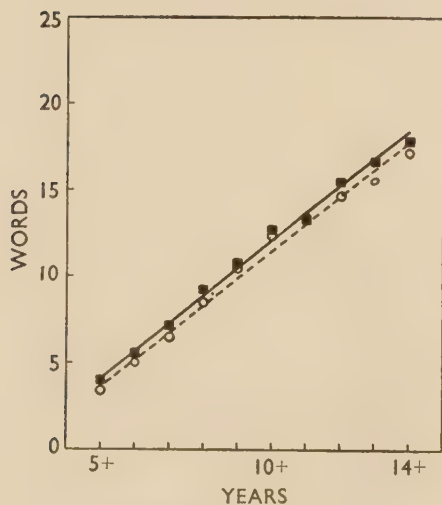
A Study of Four Vocabulary Tests



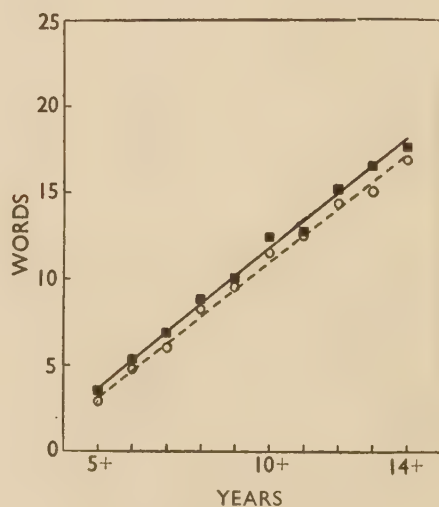
A. Vocabulary form Terman-Merrill Scale, Form L.



B. Vocabulary from Wechsler Intelligence Scale for Children.



C. Mill Hill Vocabulary Scale A.



D. Mill Hill Vocabulary Scale B.

FIG. 1.—Mean Numbers of Words Defined by Years of CA, with Fitted Linear Regressions.

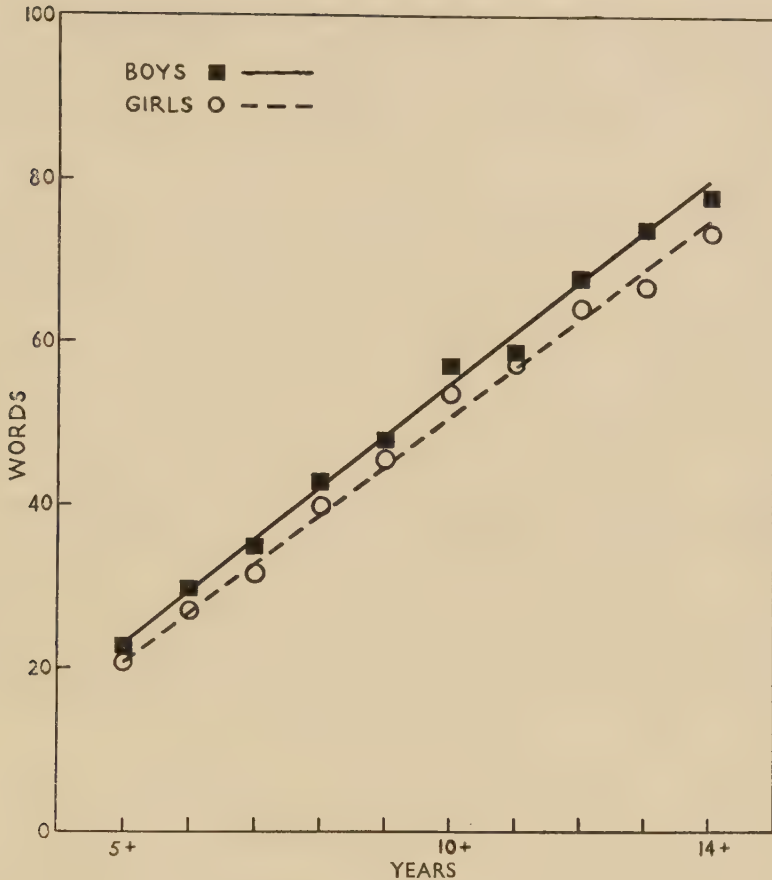


FIG. 2.—All four Vocabularies combined. Mean Number of Words Defined by Years of CA, with Fitted Linear Regressions.

which he suspected might be even slightly more familiar to one or other sex. Nevertheless, the sex difference in his vocabularies is much the same as that shown by TML and WISC, in which, as Professor Terman and Dr. Wechsler inform us, no such exclusion of words was practised.

Another sex difference, of a more familiar kind, also appears in our sample. It has often been noted that boys are more variable in performance than are girls; and this emerges in a striking way from the present data. The detailed variances at fixed CA are shown in Table V. It is hoped to make more detailed use of this information in another paper.

(e) *Intercorrelations of the Four Vocabularies.* The intercorrelations between the scores on the four vocabularies at fixed CA are shown in Table VI.

The intercorrelations seem reasonably high, particularly when it is recalled that they refer to tests taking only a few minutes to give. Naturally they are lower than reliability coefficients based on the repetition of the same vocabulary; these, as mentioned in the previous paper, seem to be generally about .9. In a sense, the

A Study of Four Vocabulary Tests

intercorrelations may be regarded as another kind of reliability coefficient, measuring the consistency of performance in the task of word definition generally, apart from consistency in regard to a particular set of words.

The intercorrelations are appreciably higher with the boys. No doubt this is a reflection of the wider dispersion of their performance, as shown in Table V.

TABLE V. VARIANCE OF WORDS DEFINED AT FIXED CA

	Boys	Girls	Ratio Boys/Girls
TML . . .	14.45	10.81	1.34
MHA . . .	11.09	8.52	1.30
MHB . . .	11.68	9.51	1.23
WISC . . .	11.43	9.01	1.27
Total . . .	171.09	128.67	1.33

For both boys and girls the intercorrelations show relatively little variation in magnitude, except that, as might be anticipated, the correlation between the two forms of the Mill Hill test (MHA and MHB) gives the highest figures.

TABLE VI. INTERCORRELATIONS OF THE SCORES ON THE FOUR VOCABULARIES

Partial Correlations at fixed CA			
Boys	MHA	MHB	WISC
TML . . .	.8347	.8476	.8233
MHA . . .		.8717	.8314
MHB . . .			.8457
Girls	MHA	MHB	WISC
TML . . .	.7775	.8024	.7730
MHA . . .		.8317	.8094
MHB . . .			.8234

(f) *Comparison with the Previous Sample.* The present results can be compared, for TML only, with those obtained from the previous sample (Dunsdon and Roberts, 1953). For the means, adjusting to 10.80 years, as used with the previous sample, the figures are as follows:

	<i>Present sample</i>	<i>Previous sample</i>
Boys	14.01	13.43
Girls	13.04	12.81

The figures for increment of words per year of CA are:

	<i>Present sample</i>	<i>Previous sample</i>
Boys	1·64	1·67
Girls	1·53	1·55

The regressions are thus almost identical; but the mean performance of the present sample of children is $\cdot58 \pm \cdot28$ words higher in boys and $\cdot23 \pm \cdot27$ words higher in girls. In view of the very different ways in which the samples were made up, it is satisfactory to find that the discrepancies are so small. The sample of 500 test-results used in the previous paper was made up from available report-forms for children who had been tested for a wide variety of purposes, these being selected (using random processes) so as to give a group with a mean I.Q. of 103 and a standard deviation of 17. A large number of the forms, however, were those of brothers and sisters of mental defectives, and few independent school children were included. It might well have been anticipated that a highly verbal test, such as vocabulary, would reflect the lower social background, which such a sample might be expected to show, more clearly than would the Terman-Merrill Scale as a whole. It is, therefore, reassuring to find that the difference between the results in the earlier sample and those obtained from an effectively random sample is barely significant in the boys and not significant in the girls. The sex difference pointed out in the previous paper is now, of course, amply confirmed.

It may also be noted that the correlation between TML vocabulary score and MA on the whole scale, at fixed age, as then discovered, was $\cdot84$ —a figure which is of the same order of magnitude as the correlation of the TML vocabulary score with the three other oral definition tests, as shown in Table VI.

III. THE INCLUSION OF INDEPENDENT AND PRIVATE SCHOOLS

In our sample 10 per cent. of the boys and 7 per cent. of the girls attended independent and private schools. The results for these children separately are not of much general interest. In other cities the proportions and kinds of children attending these schools might well be quite different. Moreover, there are features in the selection from these schools which make the results somewhat unreal. For example, mean age is substantially higher than in the remainder—19 months in the boys and 14 months in the girls. This reflects a tendency for children to enter these schools at later ages—for example, the very bright children awarded special places as the result of the examination at 11+. The regressions therefore are much distorted. What is important is to see what the effect would be if a survey of the present kind were to be restricted to children attending the Local Education Authorities schools. It is sufficient to quote the results for one vocabulary only, namely, TML. For boys, the figures are as follows:

	<i>Whole Sample</i>	<i>Sample omitting Independent and Private Schools</i>
Mean score at 114·8 months . .	11·98	11·37
Increment of words per year . .	1·64	1·46
Variance of words at fixed CA . .	14·45	10·14

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The differences are rather less for the girls, but still substantial. It is clear, therefore, that the omission of independent and private schools would very seriously alter the results, and lead to norms that would be appreciably different from those of the whole child population.

IV. ABSENTEES

The results for absentees (74 boys, 76 girls) are in sharp contrast to those just described. Absentees are lower in performance; but the differences are not great, and omission would in fact have made relatively little difference. The results, again for TML, are as follows:

<i>Boys</i>	<i>Whole Sample</i>	<i>Sample omitting Absentees</i>
Mean words at 114·8 months . . .	11·98	11·99
Increment of words per year . . .	1·64	1·66
Variance at fixed CA . . .	14·45	14·61
<i>Girls</i>		
Mean words at 114·8 months . . .	11·16	11·22
Increment of words per year . . .	1·53	1·55
Variance at fixed CA . . .	10·81	10·97

A number of earlier studies have shown that children absent on the date of school visiting are often appreciably lower in score than the remainder; and we were surprised to find relatively modest differences in the present sample. It may be that the pattern of absenteeism is changing. To mention two possible reasons for this, there are the material benefits now offered by the schools (for example, free meals), and there is the fact that more mothers are out at work during the day. Nevertheless, one would hesitate to suggest that absentees could safely be omitted from a survey of this kind—at least until the relative lack of difference had been confirmed with other samples in other areas. It may be that our sample of absentees proved rather peculiar in this respect; and, until a good deal of confirmatory evidence is forthcoming, there would always be a doubt whether the results had not been fairly seriously distorted. Moreover, even in our sample, the effect of omission of absentees, though relatively small, cannot, in the girls at least, be called negligible.

V. SUMMARY

1. A 3 per cent. sample of the schoolchildren of the City and County of Bristol was selected, by visiting all schools (including a number outside the city) and choosing those children, between the ages of 5·0 to 14·11 years, whose homes were within the city and whose birthdays fell on the first day of any calendar month. Four vocabulary scales were used: that from the Terman-Merrill Scale, Form L; Mill Hill Vocabulary A and B; and that from the Wechsler Intelligence Scale for Children.

2. The present paper gives the first results. The establishment of norms will be dealt with later.

3. All four vocabularies proved to be sex-biased in favour of boys, who on the average defined more words at every age studied. The differences were fairly substantial; and all were highly significant.

4. In 5 out of 8 comparisons given by 2 sexes and 4 vocabularies the increment of score with CA showed no significant departure from linearity. Three showed some divergence. There was no significant departure from linearity in the combined score for all vocabularies.

5. The intercorrelations of the four scores, reduced to fixed age, were of the order of rather more than .8; they showed little variation in magnitude.

6. It is shown that omission of children attending private and independent schools would have distorted the results very seriously: on the other hand, absentees on the dates of the original visits to the school were not greatly lower in performance than the remainder, and their omission, in this particular sample, would not have altered the results very appreciably. It is not suggested, however, that this would be in general a safe procedure.

Acknowledgments. We are most grateful to Professor Lewis M. Terman and to the Houghton Mifflin Company for permission to use the Vocabulary test from the Terman-Merrill Intelligence Scale (1937); to Mr. J. C. Raven for permission to use the Oral Definitions Form of his Mill Hill Vocabulary Scale; and to Dr. David Wechsler for allowing us to use the Vocabulary from his Intelligence Scale for Children. Special thanks are due to the Bristol Education Committee and to the Chief Education Officer, Mr. G. H. Sylvester, who gave permission for work to be carried out in their schools, and in particular to the Headmasters and Headmistresses of both the Local Education Authority's schools and Independent Schools, without whose willing and active co-operation the children would not have been available.

In the collection of data and in its subsequent analysis, helpful assistance has been given by Miss M. E. Drabble and Mr. J. Annett, Assistant Psychologists at the Burden Mental Research Department. We are indebted to Miss L. D. Buswell for drawing the figures.

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AN ADDITIVE METRIC FROM ALL THE PRINCIPAL COMPONENTS OF A PERFECT SCALE¹

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Abstract. A new type of metric is established for perfect scales that is different from the three previously known types of metrics. Given a perfect scale of m types of dichotomous items, each rank of persons is regarded as a point in an m -dimensional space defined by the m non-constant principal components. A non-Euclidean distance function is defined for this space. It is proved that the resulting metric is additive: the non-Euclidean distance between any two ranks i and k is the sum of the distances from i to j and from j to k whenever $i \leq j \leq k$. Treating the principal component space as non-Euclidean may also be useful for the study of non-scale structures and of quasi-scales.

I. *Introduction.* II. *A Numerical Example of Principal Component Scores.* III. *Making each Principal Component's Variance Proportional to its η^2 .* IV. *The Non-Euclidean Distance Function and the New Additive Metric.* V. *Possible Applications for Non-Scalable Universes and for Quasi-Scales.* VI. *Proof of the Additive Property of the New Metric.*

I. INTRODUCTION

Three different meaningful metrics are known for a perfect scale, and have been described elsewhere [2, 3]. They are, respectively: (a) the basic rank order of the population; (b) the first principal component scores, which maintain the basic rank order, but stretch and contract differences in rank to give a best metric in a certain sense of least squares (as defined in [1]); (c) 'absolute psychological types,' or the *intervals* along the basic rank order, defined by the bending points of the successive principal component curves.

In the present paper we shall prove that every perfect scale always has also a fourth type of metric, and that this is an *additive* metric. The new metric is computed in an exact algebraic fashion from *all the principal components* of the perfect scale. In this new metric, if i , j , and k are any three scale ranks, and if j is between i and k , then the distance from i to k is the sum of the distances from i to j and from j to k .

We shall first illustrate the new metric and its additive property by a numerical example, and shall give it an interpretation. Then we shall prove algebraically that the additive property holds for all perfect scales.

II. A NUMERICAL EXAMPLE OF PRINCIPAL COMPONENT SCORES

For illustrative purposes, let us take the example published in [2] of a perfect scale of five types of dichotomous items, where all the principal components have been worked out numerically. Five types of dichotomous items yield six ranks (types) for persons and five

¹ This research was facilitated by an uncommitted grant-in-aid to the writer from the Behavioral Sciences Division of the Ford Foundation.

An Additive Metric from All Principal Components

principal component scores for each rank, apart from a constant score (on the constant principal component). Given that the types of items are all equally frequent in the universe of items, and that the types of persons are all equally frequent in the population of individuals (respondents), the principal component scores of the scale turn out to be numerically as in Table I.

TABLE I. RAW PRINCIPAL COMPONENT SCORES FOR EACH RANK OF PERSONS¹

Rank of Persons	Principal Component				
	I	II	III	IV	V
5	5	5	5	1	1
4	3	-1	-7	-3	-5
3	1	-4	-4	2	10
2	-1	-4	4	2	-10
1	-3	-1	7	-3	5
0	-5	5	-5	1	-1
η^2	.6	.2	.1	.06	.04
Raw sum of squares	70	84	180	28	252

¹ From [2], Table IV, p. 322.

We have copied the principal components' scores in Table I in the same raw form as given in [2, p. 322]. These are raw scores in the following sense: each principal component is a latent vector of a certain matrix. Latent vectors are defined only up to a constant of proportionality, that is, multiplying any column of scores in Table I through by any (non-zero) constant will yield new scores on what is actually the same principal component; geometrically, the *direction* of the latent vector remains unchanged—except possibly for sign—and only its *length* is affected. The length of any given latent vector in Table I is the square root of the corresponding sum of squares shown in the last row of the table.

III. MAKING EACH PRINCIPAL COMPONENT'S VARIANCE PROPORTIONAL TO ITS η^2

For purposes of exposition in [2] the raw scores in Table I were deliberately computed to be in exact whole numbers. This has made the raw sums of squares—and hence the lengths of the corresponding latent vectors—arbitrarily unequal. For some theoretical purposes, it is useful to make the lengths of all latent vectors equal, say equal to 1; this can be done for the data of Table I by dividing each raw score in a given column by the square root of its raw sum of squares. For each column the sum of squares of the new scores will then always be 1.

For our present purpose, as a first step toward our new metric, we need to modify the lengths of the latent vectors in a different manner, namely, to make each new sum of squares equal to the corresponding η^2 . One motive for this is as follows. The components were arrived at in the first place from a maximization problem: given the responses of a population of individuals to a universe of items, find that set of scores—or metric—for the individuals which will maximize the correlation ratio over items [1]. The maximizing scores turn out to be the *first* principal component of the set of responses, and so give the *best metric* in this sense of maximization. But the same equations show that there also exist *next best* down to *worst* principal components, as ranked by the correlation ratios they yield. The sum of squares of all correlation ratios is 1 [cf. 2, p. 322], showing that the

total variance of the responses can be accounted for exactly and in a *linear fashion* by all the principal components. (The linear equations for reproducing the original item responses exactly from all the principal component scores are illustrated in [2, pp. 331 f.].) In this sense (and since the principal components for a perfect scale are always orthogonal to each other), the η^2 associated with a given principal component expresses its proportional contribution to the total variance of the scale.

Therefore, in making the length of each principal component vector equal to the η of that component, we are expressing each component in a way which reflects its importance for accounting for the observed data in a linear fashion. The first component is given the largest variance, the last component the smallest variance, and intermediate components variances of intermediate size.

To convert the raw scores of Table I into the proportional form that we desire, it is necessary simply to divide each row by the square root of its raw sum of squares and then multiply by η . This can be done in one step by multiplying each row by the quantity $\sqrt{\{\eta^2/(\text{raw sum of squares})\}}$. Thus, each raw score in the first column of Table I is to be multiplied by $\sqrt{\{.6/70\}} = .09258$. For the remaining columns the multipliers are $\sqrt{\{.2/84\}}$, $\sqrt{\{.1/180\}}$, $\sqrt{\{.06/28\}}$, and $\sqrt{\{.04/252\}}$ respectively. The new scores are shown in Table II.

Here we are omitting the constant component throughout, because it does not affect our new metric. The correlation ratio is actually zero for the constant component, although its latent root is 1; for each of the other principal components, η^2 is always equal to the corresponding latent root.

TABLE II. PRINCIPAL COMPONENT SCORES¹Expressed with Sum of Squares equal to η^2

Rank of Persons	Principal Component				
	I	II	III	IV	V
5	.4629	.2440	.1179	-.0463	-.0126
4	.2771	-.0488	-.1650	-.1389	-.0630
3	-.0926	-.1952	-.0943	-.0926	-.1260
2	-.0926	-.1952	.0943	.0926	-.1260
1	-.2771	-.0488	.1650	-.1389	-.0630
0	-.4629	.2440	-.1179	-.0463	-.0126
η^2	.6	.2	.1	.06	.04
Sum of squares	.6	.2	.1	.06	.04

¹ Computed from Table I by multiplying each column of raw scores of Table I by $\sqrt{\{\eta^2/(\text{raw sum of squares of that column})\}}$.

IV. THE NON-EUCLIDEAN DISTANCE FUNCTION AND THE NEW ADDITIVE METRIC

We are now in a position to introduce our new overall metric. In Table II, each rank (row) has five component scores. Since each pair of components is orthogonal over all persons, the five components can be regarded as providing an orthogonal coordinate system of a five-dimensional Euclidean space, and each rank of persons can be thought of as a point in this five-space.

Let us now inquire about the *distance between each pair of ranks* in this five-space. The Euclidean definition of distance between two points requires us to take the *square root*

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of the sum of squares of the differences between the corresponding coordinates of the two points. Thus, in the five-space of Table II, the Euclidean distance between ranks 5 and 4 is $\sqrt{.24}$, since

$$(.4629 - .2771)^2 + (.2440 + .0488)^2 + (.1179 + .1650)^2 + (.0463 + .1389)^2 + (.0126 + .0630)^2 = .24.$$

For the purposes of our new metric, it turns out to be more profitable to regard the five-space of Table II as a *non-Euclidean* space, by defining the distance between two points to be the *square* of the Euclidean distance: that is, we shall dispense with taking square roots as required by the Euclidean metric. Accordingly, our non-Euclidean distance between ranks 5 and 4 is .24, in distinction to the Euclidean distance of $\sqrt{.24}$. The non-Euclidean distances between each pair of ranks of Table II are given in Table III.

TABLE III. THE NON-EUCLIDEAN DISTANCES

The Euclidean-Distances-Squared between each Pair of Ranks in the Five-Space defined by the Principal Components in Table II

Rank of Persons	Rank of Persons					
	5	4	3	2	1	0
5	0	.24	.39	.52	.67	.91
4	.24	0	.15	.28	.43	.67
3	.39	.15	0	.13	.28	.52
2	.52	.28	.13	0	.15	.39
1	.67	.43	.28	.15	0	.24
0	.91	.67	.52	.39	.24	0

A striking feature of Table III is immediately apparent. If $i < j < k$, then the distance from rank k to rank i is greater than the distance from rank k to rank j . Thus, the distance between rank 4 and rank 0 is greater than the distance between rank 4 and rank 1 (.67 as compared with .43). But the distances between adjacent ranks are not necessarily equal; for example, rank 5 is farther from rank 4 than rank 4 is from rank 3 (.24 as compared with .15).

The properties described in the preceding paragraph would hold also were the Euclidean distance function (or any other monotonely related distance function) to be used. Our particular non-Euclidean distance function has the following distinctive feature: the distance between any two ranks i and k is precisely the sum of the distances from i to j and from j to k , where j is any rank intermediate to i and k . For example, rank 3 is intermediate to ranks 4 and 1; the distance from rank 4 to rank 3 is .15, while from rank 3 to rank 1 it is .28. We have $.15 + .28 = .43$; and .43 is also the distance between ranks 4 and 1 as computed independently from Table II and recorded in Table III.

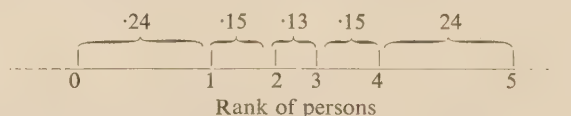


FIG. 1.—The Ranks of Persons Plotted on a Straight Line with Intervals as Defined by the Non-Euclidean Distance Function of Table III.

This additive property of our non-Euclidean distance function implies that we can mark off our ranks of persons as points along a straight line, the distances between the points being proportional to the values given by this distance function, as shown in Fig. 1. All the entries in Table III can be reproduced from Fig. 1. The distance between any two ranks is the sum of the lengths of all intervals between them in Fig. 1.

The new metric portrayed in Fig. 1 maintains the original scale rank order of the types of persons, just as do the previously known three other kinds of metric. It gives distances between the ranks which are different than from those given by the metric that is best in the sense of least squares (the first principal component). The least-squares metric is derived by obtaining projections of the ranks on a best *single* continuum. Our new metric looks at all the ranks as in a complete multi-dimensional space, and does not take projections on only one of the components of that space. We now see that, if we measure distances in a certain non-Euclidean manner, the scale ranks all lie on a 'straight line' in the resulting non-Euclidean space.

V. POSSIBLE APPLICATIONS FOR NON-SCALABLE UNIVERSES AND FOR QUASI-SCALES

It is not clear at present what further implications the new metric has for the theory of perfect scales as such, or for the psychological interpretations of scales (as from the metric of absolute psychological types discussed in [3]). It may have important applications in the analysis of *non*-scalable data.

The general equations for the principal components of qualitative data hold whether the data form a perfect scale or not, and indeed were derived in [1] before the theory of perfect scales of [2] was developed. Any set of qualitative items can be regarded as establishing an n -dimensional coordinate system of principal components for any population of respondents; and each person can be regarded as a point in this space. Tables analogous to Tables II and III above can be computed. Inspecting the distances between the persons can sometimes show that the points lie on some simple surface, if not on a straight line as in the case of a scale. This would give a means of analysing simple non-scale structures. It may turn out that, for some non-scale structures, a different non-Euclidean distance function may be more appropriate than the present function. The new type of metric may also prove helpful in studying quasi-scales. A problem to be explored is the effect on the new metric of errors of reproducibility. It may be that the new metric actually defines a class of quasi-scales, for it may possibly be perfectly additive for data which do not form a perfect scale, according to the mathematical analysis below.

VI. PROOF OF THE ADDITIVE PROPERTY OF THE NEW METRIC

The numerical example worked out above was for a special case of five types of items, and where uniform frequencies (rectangular distribution) were assumed both for the types of persons and the types of items. Different frequencies would yield different principal component scores from those of our example. We shall now show that the additive property holds for any frequency distribution, and for any number of items. While our analysis is the same as for dichotomous items, this entails no real loss of generality; for any item can be reduced to dichotomous form, or expressed as a set of dichotomies.

We shall use the results of [2] and essentially the same notation. As in [2], we may consider a perfect scale of m types of dichotomous items, yielding $m + 1$ types of persons ranked from 0 to m , and which is resolved into a set of $m + 1$ principal components. Let f_i denote the relative frequency of the i th rank of persons ($i = 0, 1, \dots, m$), and let x_{ai} denote the score of the i th rank on the a th principal component ($a, i = 0, 1, \dots, m$).

For convenience, the numbering of the principal components will be regarded as being in opposite order of the size of the corresponding latent roots. In particular, $a = 0$ denotes the *constant* principal component (with latent root 1). Since the component scores are determined only up to a constant of proportionality, we can normalise them so that

$$\sum_{i=0}^m f_i x_{ai}^2 = 1 \quad (a = 0, 1, \dots, m). \quad (1)$$

An Additive Metric from All Principal Components

In [2] it has been proved that all latent roots are distinct, so that any two different principal component score vectors are necessarily orthogonal to each other with weight function f_i . Given also (1), the $m + 1$ components yield an orthonormal set, or

$$\sum_{i=0}^m f_i x_{ai} x_{bi} = \delta_{ab} \quad (a, b = 0, 1, \dots, m), \quad (2)$$

where δ_{ab} is Kronecker's delta (equals 1 if $a = b$, and 0 if $a \neq b$).

Equations (2) imply that the square matrix of order $m + 1$, $\| \sqrt{f_i} x_{ai} \|$, is an orthogonal matrix. This matrix must then be orthonormal by rows as well as by columns, i.e.

$$f_i \sum_{a=0}^m x_{ai} x_{aj} = \delta \quad (i, j = 0, 1, \dots, m). \quad (3)$$

Let η_a^2 be the correlation ratio squared of the a th principal component. Then $\eta_0^2 = 0$; for the constant component has no variation, although the latent root for this component is 1. Our new metric, as illustrated in sect. IV above, defines the non-Euclidean distance between two ranks i and j to be $d(i, j)$, where, recalling we already have normalised the x_{ai} according to (1),

$$d(i, j) = \sum_{a=1}^m \eta_a^2 (x_{aj} - x_{ai})^2 \quad (i, j = 0, 1, \dots, m). \quad (4)$$

This metric will be additive if, and only if, for any three ranks i, j , and k (where $i \leq j \leq k$) the following property holds:

$$d(i, k) = d(i, j) + d(j, k) \quad (i \leq j \leq k). \quad (5)$$

Now, the following identity is obvious:

$$x_{ak} - x_{ai} = (x_{ak} - x_{aj}) + (x_{aj} - x_{ai}). \quad (6)$$

We can square both members, multiply through by η_a^2 , sum over a , and use (4) to obtain the further identity

$$d(i, k) = d(i, j) + d(j, k) + 2 \sum_{a=1}^m \eta_a^2 (x_{ak} - x_{aj})(x_{aj} - x_{ai}) \quad (i, j, k = 0, 1, \dots, m). \quad (7)$$

Clearly (7) will reduce to (5) if, and only if, the last member of (7) vanishes whenever $i \leq j \leq k$, or

$$\sum_{a=1}^m \eta_a^2 (x_{ak} - x_{aj})(x_{aj} - x_{ai}) = 0 \quad (i \leq j \leq k). \quad (8)$$

Thus our task will be ended if we prove that (8) always holds for a perfect scale.

As a preliminary to the proof, we establish a sufficient condition for (8). Let Δx_{ai} be defined as the difference

$$\Delta x_{ai} = x_{a, i+1} - x_{ai} \quad (i = 0, 1, \dots, m-1). \quad (9)$$

Differencing will always be with respect to the second subscript, so instead of Δ_i we shall write Δ throughout. If $j > i$, then we can write, using (9),

$$x_{aj} - x_{ai} = \sum_{s=0}^{j-i-1} \Delta x_{a, i+s} \quad (j > i). \quad (10)$$

Similarly, if $k > j$, we can write

$$x_{ak} - x_{aj} = \sum_{t=0}^{k-j-1} \Delta x_{a, j+t} \quad (k > j). \quad (11)$$

Using (11) and (10) in (8), we can write

$$\sum_{a=1}^m \eta_a^2 (x_{ak} - x_{aj})(x_{aj} - x_{ai}) = \sum_{s=0}^{j-i-1} \sum_{t=0}^{k-j-1} \left(\sum_{a=1}^m \eta_a^2 \Delta x_{a, i+s} \Delta x_{a, j+t} \right) \quad (i < j < k). \quad (12)$$

Let p_{ij} be defined by:

$$p_{ij} = \sum_{a=1}^m \eta_a^2 \Delta x_{ai} \Delta x_{aj} \quad (i, j = 0, 1, \dots, m-1). \quad (13)$$

Clearly, a *sufficient* condition for the righthand member of (12) to vanish is that $p_{i+s, j+t} = 0$ for all s and t in the given ranges for the respective i, j , and k . Surely, then, a sufficient condition for the right member of (12) always to vanish is that:

$$p_{ij} = 0 \quad (i \neq j; i, j = 0, 1, \dots, m-1). \quad (14)$$

If we prove (14), we shall have proved (8) via (12), and hence (5) via (7). The left member of (8) is identically zero if $i = j$ or $j = k$, and hence we need consider the case only where $i < j < k$, as we shall now do via (14).

For the proof of (14), we shall use the *difference equations* of the perfect scale derived in [2]. These equations can be written in the following form, suitable to our present purposes [cf. 2, p. 345, equations (51)-(53)]:

$$c_0 \Delta x_{a0} = -\frac{1}{\eta_a^2} - f_0 x_{0a} \quad (a = 1, 2, \dots, m) \quad (15)$$

$$c_{i+1} \Delta x_{a, i+1} - c_i \Delta x_{ai} = -\frac{1}{\eta_a^2} f_{i+1} x_{ai, i+1} \quad \left(\begin{array}{l} i = 0, 1, \dots, m-2 \\ a = 1, 2, \dots, m \end{array} \right) \quad (16)$$

$$c_{m-1} \Delta x_{a, m-1} = \frac{1}{\eta_a^2} f_m x_{am} \quad (a = 1, 2, \dots, m). \quad (17)$$

We have modified the notation slightly from that in [2]. Our present c_i are n/N times those of [2, equation (34)], and our $1/\eta_a^2$ are n/N times the ϕ of [2, equation (35)], except for when $a = 0$. It is essential to note that $1/\eta_0^2$ is *not defined* in our present notation, because $\eta_0^2 = 0$, although ϕ_0 is defined as $\phi_0 = 0$ in [2, pp. 345 f.]. Our present equations (15) through (17) are not stated for the constant component, to which we have to give special attention in the algebra that follows.

Let x_0 be the common constant value of the x_{0i} ($i = 0, 1, \dots, m$). Under condition (1) above, x_0 is fixed by $x_0^2 \sum_{i=0}^m f_i = 1$. Explicitly, if $\sum_{i=0}^m f_i = N$ as in the notation of [2, equation (4)], then $x_0 = \sqrt{(1/N)}$. From (3), if we take the case $a = 0$ out of the summation and write it separately, we can state for $i \neq j$ that

$$f_i \sum_{a=1}^m x_{ai} x_{aj} = -f_0 x_0^2 \quad (i \neq j; i, j = 0, 1, \dots, m). \quad (18)$$

Taking the first difference of both members of (18) with respect to j , and dividing by f_i , shows that

$$\sum_{a=1}^m x_{ai} \Delta x_{aj} = 0 \quad \left(\begin{array}{l} i \neq j, j+1; \\ i = 0, 1, \dots, m \\ j = 0, 1, \dots, m-1 \end{array} \right). \quad (19)$$

Now, if we multiply both members of (15) through by $\eta_a^2 \Delta x_{aj}$, sum over a , and use notation (13), and equation (19), we see that, since no c_i can vanish,

$$p_{ij} = 0 \quad (j = 1, 2, \dots, m-1). \quad (20)$$

Multiplying both members of (16) through by $\eta_a^2 \Delta x_{aj}$ and summing over a will similarly show that

$$c_{i+1} p_{i+1, j} - c_i p_{ij} = 0 \quad \left(\begin{array}{l} i \neq j, j+1; \\ i = 0, 1, \dots, m-2 \\ j = 0, 1, \dots, m-1 \end{array} \right). \quad (21)$$

An Additive Metric from All Principal Components

Stating (21) for $i = 0$, and using (20), now shows that

$$p_{ij} = 0 \quad (j = 2, 3, \dots, m-1). \quad (22)$$

Stating (21) for $i = 1$, and using (22), etc., shows that in general

$$p_{ij} = 0 \quad \left(\begin{array}{l} j > i; \\ i = 0, 1, \dots, m-2 \\ j = 0, 1, \dots, m-1 \end{array} \right). \quad (23)$$

But $p_{ij} \equiv p_{ji}$ from (13). Hence (23) is equivalent to (14), and we have completed the proof of the additive property (5) of our new metric.

It may be remarked that property (14) shows that, from (13), $\|\eta_a \Delta x_{ai}\|$ is a square matrix of order m that is orthogonal by columns. The Δx_{ai} are closely related to the principal components of the categories of the items in the scale, as shown by [2, equation (30)]; the weight function required for orthogonalization by rows is correspondingly implied by [2, equation (94)].

A full treatment of the related problem of category components, when items are not dichotomous but quantitative variables, is given in [4].

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THE CORRELATION BETWEEN VARIATE-VALUES AND RANKS IN SAMPLES FROM DISTRIBUTIONS HAVING NO VARIANCE

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1. In [2], it was shown that in samples of size n from a continuous distribution function $F(x)$ with mean μ and variance σ^2 , the correlation between variate-values and the corresponding ranks is given by

$$C_n = \left\{ \frac{12(n-1)}{(n+1)} \right\}^{\frac{1}{2}} \cdot \frac{\left\{ \int xF(x) dF(x) - \frac{1}{2}\mu \right\}}{\sigma}. \quad (1)$$

We now consider the problem in the case when the distribution has no variance.

Moments can fail to exist only if the range of the distribution is either singly- or doubly-infinite. In the first place, we consider only a portion of the distribution defined on an arbitrarily wide range (a, b) . For this interval, (1) holds, with a and b as the limits of integration in $\int xF dF$ and in the integrals defining μ and σ^2 .

2. Consider first the case of a singly-infinite range, say upwards. We may take a to be the lower terminal of the distribution, and take the limit of (1) as $b \rightarrow \infty$. If we write (1) as

$$C_n = K \cdot R, \quad (2)$$

we have

$$\text{Lim } R^2 = \text{Lim} \frac{\frac{a}{b} \left\{ \int_a^b xF dF - \frac{1}{2} \int_a^b x dF \right\}^2}{\left\{ \int_a^b x^2 dF - \left(\int_a^b x dF \right)^2 \right\}}. \quad (3)$$

If the mean of the distribution exists, the numerator of (3) has a finite limit; for $\int xF dF$ converges whenever $\int x dF$ does, since $0 \leq F \leq 1$. And since the denominator of (3) diverges by hypothesis, the ratio R^2 tends to zero.

The problem becomes non-trivial when the mean, as well as the variance, does not exist. We then apply L'Hôpital's rule to (3), differentiating numerator and denominator to obtain

$$\text{Lim } R^2 = \text{Lim} \frac{2(F(b) - \frac{1}{2}) \left\{ \int_a^b xF dF - \frac{1}{2} \int_a^b x dF \right\}}{\left\{ b - 2 \int_a^b x dF \right\}},$$

and on repeating the operation,

$$\text{Lim } R^2 = \text{Lim} \frac{2f(b) \left[b(F(b) - \frac{1}{2})^2 + \left\{ \int_a^b xF dF - \frac{1}{2} \int_a^b x dF \right\} \right]}{1 - 2bf(b)}. \quad (4)$$

The Correlation between Variate-Values

Now if there exists a value of x , say X , such that

$$f'(x) < 0 \quad \text{for all } x > X,$$

i.e., such that the frequency function is monotone, decreasing beyond some point, it will follow from a theorem quoted in [1], p. 124 that, even though the mean does not exist,

$$\lim b f(b) = 0. \quad (5)$$

Substituting (5) in (4), we find

$$\lim R^2 = \lim \frac{2 \left\{ \int_a^b x F dF - \frac{1}{2} \int_a^b x dF \right\}}{1/f(b)}. \quad (6)$$

Applying L'Hôpital's rule again to (6), we obtain

$$\lim R^2 = \lim \frac{-2 \{ F(b) - \frac{1}{2} \} b \{ f(b) \}^3}{f'(b)}, \quad (7)$$

and since

$$\lim F(b) = 1,$$

(7) becomes

$$\begin{aligned} \lim R^2 &= - \lim \frac{b \{ f(b) \}^3}{f'(b)}, \\ &= - \lim b f(b) \cdot \frac{\{ f(b) \}^2}{f'(b)}. \end{aligned} \quad (8)$$

From (5), using L'Hôpital's rule again,

$$0 = \lim \frac{b}{1/f(b)} = - \lim \frac{\{ f(b) \}^2}{f'(b)}. \quad (9)$$

Putting (5) and (9) into (8), we have, using (2).

$$\lim C_n = \lim R^2 = 0. \quad (10)$$

An example of the type of distribution discussed is

$$dF(x) \propto \frac{dx}{x^2}, \quad (0 < x \leq \infty)$$

which has no mean since $\int_0^\infty \frac{dx}{x}$ diverges.

3. The same result holds for a doubly-infinite range if we write $a = -b$ and interpret the integrals as principal values. For since

$$\frac{d}{db} \int_{-b}^b g(x) dx = 2 \frac{d}{db} \int_c^b g(x) dx,$$

the effect of having a doubly infinite range is simply to introduce a factor 2 whenever an integral is differentiated, and this does not change the value of the limit at (10). Thus, for example, the Cauchy distribution

$$dF(x) \propto \frac{dx}{1+x^2}, \quad (-\infty \leq x \leq \infty),$$

which has no moments and its monotone in its tails, has $C_n = 0$ by (10). We conclude that, for any continuous distribution with no moments which is ultimately monotone,

the correlation between variate-values and ranks is zero. However, this property does not characterize such distributions, for in [2] it was shown that for Gamma variates with parameter $m (> 0)$,

$$\lim_{m \rightarrow 0} C_n = 0,$$

and that generally, when the variance exists, a necessary condition for $C_n = 0$ is that $f(x)$ be unbounded at some point within its range.

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ERRATA

The following corrections should be made in the article on 'The Correlation between Variate-values and Ranks in Samples from a Continuous Distribution,' this *Journal*, VII, Pt. I, pp. 37-44.

1. P. 40, eqn. (22): Right side should be $1/(2.3^{\frac{1}{2}})$, not $1/(2.3)^{\frac{1}{2}}$.
2. P. 41, below eqn. (24): delete 'a result . . . much earlier.'
3. P. 42, end of Section V should continue: 'The result (24) for r in the normal case has been given by Burt (1953), who obtained it earlier.'
4. P. 43, Example 1, Line 5: delete 'in virtue of section V.'
5. P. 43, Example 1, Lines 6 and 7, delete: 'asymptotically' (twice).
6. P. 43, Example 1, second paragraph, Line 2: The result for asymptotic relative efficiency should read $(C^2)^{\frac{1}{2}} = (3/\pi)^{\frac{1}{2}}$, not $C^2 = (3/\pi)$ as printed.

ALAN STUART.

A NOTE ON THE USE OF BURT'S FORMULA FOR ESTIMATING FACTOR SIGNIFICANCE

BY EDWARD E. CURETON

Burt¹ gives as an approximate formula for the standard error of a centroid or simple-summation factor loading :

$$\sigma_a = (1-a^2)\sqrt{\{n/[N(n-s+1)]\}}, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a is the loading, N is the number of subjects in the sample, n is the number of tests or variables, and s is the ordinal number of the factor.

Vernon suggests that the s th factor may be considered insignificant whenever at least half its loadings fall short numerically of twice their standard errors.² It is not necessary to compute the standard errors of all n factor loadings to apply this test. If we examine (1), we see that the expression under the radical is the same for all loadings on a given factor.

Let $a/\sigma_a = k$ (according to Vernon's recommendation, k should be 2); then $a = k\sigma_a$, and from (1),

$$a = (1-a^2) C, \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\text{where } C = k\sqrt{\{n/[N(n-s+1)]\}}. \quad . \quad . \quad . \quad . \quad (3)$$

Now (2) is a quadratic in a , whose positive root is

$$a' = [-1 + \sqrt{(1+4C^2)}]/2C. \quad . \quad . \quad . \quad . \quad (4)$$

If we find C from (3) and then a' from (4), a' is the critical value of a : all loadings numerically greater than a' are significant and all loadings numerically less than a' are insignificant at the $k\sigma$ level.

EXAMPLE:

$$N = 600, n = 30, s = 11, k = 2.$$

$$C = 2\sqrt{\{30/[600(30-11+1)]\}} = \cdot 1.$$

$$a' = [-1 + \sqrt{(1+4C^2)}]/2 = \cdot 099.$$

The eleventh factor will be significant, according to Vernon's standard, if and only if more than half its loadings are numerically greater than $\cdot 099$.

¹ C. Burt and C. Banks. *Annals of Eugenics*, XIII, 255; also this *Journal*, 'Tests of Significance in Factor Analysis', v, 121, eqn. xxvi.

² Burt's criterion is more lenient: with borderline cases at least one quarter must exceed twice the standard error for the factor to be significant. But in general he also takes the size of the loading into account.

A PSYCHOLOGICAL STUDY OF TYPOGRAPHY

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Abstract. A wide variety of type-faces have now become available for books and journals. It therefore seemed desirable to investigate (A) the legibility and (B) the aesthetic merits of those in more frequent use.

(A) Using tests of speed and comprehension, we have studied the influence of type-face, boldness, size, interlinear spacing, length of line, and width of margin on legibility both with children and with adults. The results have furnished provisional norms for children's reading books and for scientific journals such as the present.

(B) Factorial methods, supplemented by an analysis of introspections, appear to yield a classification of both readers and type faces based on aesthetic preference; and the data incidentally obtained throw considerable light on the reasons for such preferences.

I. PREVIOUS INVESTIGATIONS OF TYPOGRAPHICAL PROBLEMS

Printing as a Medium of Communication. Psychologists have of late shown increasing interest in what is called 'the theory of telecommunication', that is, communication between persons who are not within visible or auditory range of each other.¹ The statistical treatment of the issues involved, which is the most distinctive feature of the 'theory', has been developed primarily in connection with telephonic engineering; and, perhaps largely for this reason, the attention of the psychologist has been concentrated mainly on auditory methods of transmission. But communication by visible symbols is not only the oldest but by far the commonest method of imparting information to a distant recipient; and the problems of setting up print and reading print—the most thoroughly standardized of all such devices—are equally amenable to the same mode of analysis.

If we take the 'phoneme'² as the unit of information, the English language presents us with a fairly well defined ensemble of alternative elements—12 vowels and 37 consonants—which the printer proceeds to encode by using an alphabet of 26 visible signals, each of which may have four different forms, roman, italic, upper case (or capital), and lower case. Analogous to the audible 'noise' which interferes with the accurate transmission of the audible information, there is a visuo-mental interference or 'blur', which impedes the accurate transmission of visible information. Accordingly, just as the intelligibility of a wireless message is measured by a logarithmic function of the signal-to-

¹ Cf. Burt, this *Journal*, IV, pp. 195-200; also D. MacKay, 'Quantal Aspects of Scientific Information', *Phil. Mag.*, LXIII (1950), G. A. Miller, *Language and Communication* (New York, McGraw-Hill, 1951), and C. E. Shannon, 'Communication Theory: Exposition of Fundamentals' (London, Ministry of Supply, 1953).

² Otto Jespersen, *Lehrbuch der Phonetik* (1916), Daniel Jones, *Outline of English Phonetics* (1928). Any phonetic symbol, ϵ (for example), represents, not an invariable speech-sound made with the vocal organs always in the same place, but a family of ϵ -sounds varying slightly (even with the same speaker) according to the vocal context. Such a family is termed a 'phoneme'. The neglect of this fact is a common source of trouble in teaching children, particularly backward children, to read: see Burt, *The Backward Child*, Appendix IV and refs. It may be noted that three more phonemes are needed to represent standard American speech.

noise ratio, so the intelligibility of a printed message could be measured by a similar function of what we might call the symbol-to-blur ratio.¹

As was perhaps only natural for the engineer, the formulae which he has developed to measure information treat the efficacy of the signalled message as a kind of 'energy' or capacity for doing work, and its negative is represented by an expression similar to that adopted by Boltzmann in formulating 'entropy' in terms of probability. However, for our present purpose it seems desirable to take account of yet another variable characteristic. Of two media enabling the same message to be communicated to the same recipient with the same accuracy, that which delivers the information the more speedily must plainly be regarded as the more effective. The consideration of speed of reading therefore adds a further complication to the problem, and should perhaps lead us to look for some formula which will enable us to measure the 'power' of the media.

We believe that the adoption of the concepts and methods employed in the theory of communication would greatly increase the logical rigour of the psychologist's investigations. But we are somewhat doubtful whether, in the existing stage of knowledge, the use of the corresponding algebraic formulae will be of much service. Psychological measurements are so crude and inexact that the elaborate mathematical refinements of these newer techniques seem out of place. In any case, the following article is intended merely as a preliminary exposition; and it has been our aim to make it comprehensible to teachers and others with no special knowledge of advanced statistical theory. For the most part, therefore, we shall for the present keep to the simplest possible methods of assessment; and measurements of accuracy and speed will be reported separately in terms of units of time and of ideational items. We shall begin by investigating the ways in which the visible appearance of printed matter aids or hinders the communication of the ideas which it seeks to express, in a word, the conditions affecting *legibility*.

II. LEGIBILITY

The Legibility of Children's Reading Books. In this country the typographical questions which have chiefly attracted the attention of the psychologist relate to the sizes and shapes of the letters used for printing children's reading books. Even on these points the number of British investigations has been surprisingly few; and those who are concerned with the selection of suitable type for reading books or for verbal tests are still guided (so far as they pay any consideration to the matter at all) by recommendations put forward nearly forty years ago.

In 1912 a committee was appointed by the Education Section of the British Association to investigate 'the influence of school books upon eyesight'. In order to secure evidence on certain of the questions then raised, Burt (at that time Psychologist in the Education Department of the London County Council) and James Kerr (then Medical Officer in the same Department) carried out a number of investigations among children in London schools. It was agreed that Dr. Kerr should deal with the clinical aspects, while Burt undertook a series of experiments in the classroom and in the laboratory. The Council's printer generously supplied us with a wide variety of test-sheets printed to our own specifications.

The results of our investigations were summarised in the L.C.C. Annual Reports and later in Dr. Kerr's larger treatise [7].² The Final Report of the Committee of the British Association [2] was published in 1917; and included a tabulated set of standards showing the size of type and the style of printing suited to pupils of different ages. Most of the school books since published by the more competent firms have conformed fairly closely with the standards then laid down.³ During

¹ One of our chief methodological difficulties has been to decide whether to take the letter or the word (and their respective significations) as our unit. In applying the theory of communication to the study of the child's speaking vocabulary, Burt preferred to take the word as unit (cf. this *Journal*, *loc. cit. sup.*, p. 199 and refs.); and, as will be seen later, we have in the present series of experiments kept mainly to words or ideational units. Most psychologists who have investigated legibility have limited themselves to the legibility of isolated letters. But with modern methods of teaching children to read, the legibility of the word as a whole is even more important than the legibility of the constituent letters. The two modes of measurement do not always yield the same result. A complete investigation requires the use of both.

² Cf. also Burt [3], pp. 271, 340-1. Dr. Kerr's standards for size and interlinear space are not quite so generous as those of the Brit. Assoc. Committee. A review of practices generally current before these inquiries will be found in a paper by Mr. G. F. Daniell (Chief Examiner to the London County Council) in the *Annual Report* of the Brit. Assoc. for 1911, p. 633. After the first World War, a suggestive monograph was published by the Stationery Office (L. A. Legros, *Note on the Legibility of Printed Matter*, 1922; cf. also [4]). See also R. D. Morss, 'The Neglected School Book', *Monotype Recorder*, XXXIV, 1935, pp. 5f.

³ A fairly comprehensive summary of the chief American investigations will be found in [22], chap. IV (pp. 101-25; see also bibliography, pp. 452-74). But the reader who has no easy access to the original articles will at times be disappointed to find that the age of the subjects of the experiments is seldom stated. Occasionally, too, the data are said to yield significant differences between two or more different modes of printing, but the authors omit to state in what direction the differences pointed.

the next ten years a series of laboratory researches, often involving highly skilled techniques, were carried out in America [9-14]. But since the Second World War little fresh work has apparently been attempted in either country. Owing to the great advances in printing during the last two or three decades, and the wide variety of types meanwhile introduced by the Monotype Corporation and other foundries, it seems highly desirable that the problems should be taken up afresh.

A few years ago, when the British Psychological Society proposed to establish a journal of statistical psychology, Burt, with the help of several research students, began a series of preliminary investigations on legibility and typographical preferences among educated adults; and the more recent decision of the Society to reconsider its choice of printer has furnished an additional reason for ascertaining the views of potential readers and subscribers to this journal. The appeal inserted in the last issue has elicited numerous comments and replies; and we should like to thank our correspondents for their help. With the aid of teachers and others, we have continued and considerably extended the earlier experiments on school children. The account that follows will summarize, as succinctly as possible, the main conclusions that have so far emerged. As so often happens, one of the most valuable results has been to show where the methods adopted were at fault and to indicate more effective lines of inquiry.

Methods. To determine the legibility of type, a large variety of methods have been employed by previous investigators. The commonest may be broadly classified as follows:

1. Ease of reading letters, words, or sentences, judged by the distance at which they can be read.
2. Accuracy of reading letters or words with brief tachistoscopic exposures.
3. Speed of reading passages of prose, when the reader's aim is to grasp the content of the passages.
4. The observation of eye-movements, eye-blinking, and other objective symptoms.

There can, we think, be little doubt that the results obtained often depend very largely on the experimental procedure used. For example, types that appear more legible than others when tested by the distance method may prove less legible when tested by speed of reading.

We ourselves found the first two methods quite effective for investigating the legibility of isolated letters or figures, particularly where the shape is apt to differ according to the style of type. For our main purpose, however, which was to determine the legibility, not of isolated words or characters, but of consecutive sentences, such procedures proved inappropriate. With children the study of eye-movements, fixation-time, blinking, and the like was at times informative, especially in the case of young or backward readers, and of those who suffered from minor visual defects. But on the whole, its value was merely supplementary; it might often explain why certain styles of printing were unsuitable, but it did not afford a practicable basis for systematic comparison. The method therefore on which we have principally relied consisted in getting each reader to read silently a page of simple consecutive prose, timing his speed, and then determining by means of a questionnaire how much of the details had been grasped.

For the preliminary experiments children were tested in class, and a fixed time-limit was imposed. For the final experiments individual testing was adopted, and proved far superior to group testing. Every child was asked to read aloud an entire page, which had been devised to form a unit complete in itself; the time required was measured with a stop-watch, and the questions answered orally.¹ At the same time a careful look-out was kept for pauses, irregular eye-movements, and other signs of difficulty or fatigue.

In the later stages of our work we introduced an important modification. We became gradually convinced that short tests, such as have been used by many previous investigators, can often be quite uninformative and at times positively misleading. In changing to a fresh or unfamiliar type-face, the reader needs time to become adequately adapted. Moreover, differences in legibility and fatigability may not appear during the first few minutes: many readers who can read 8-point as accurately and as quickly as 10-point, provided only a brief paragraph has to be read, often show signs of strain with the smaller types after they have been reading one or two pages. Accordingly, instead of handing the reader the essential test-passages straightaway, we first gave him a preliminary booklet printed in the same style of type and kept him reading it for 5 minutes, before subjecting him to the final test.

¹ In the earlier experiments much of the testing was carried out by Mr. T. R. Kingsley (who had had considerable experience in an Institute where printing and book-making were regular subjects) and by Miss Violet Pelling. In the more recent experiments most of the testing has been carried out by Mr. W. F. Cooper and by Miss J. L. Martin, who therefore appear as joint authors.

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Influence of (a) Type Faces. The legibility of a page of print is the resultant of many different factors—the size, the form, the thickness or ‘boldness’ of the letters, the width of the line, the distance between successive lines, the texture of the paper, and the intrinsic interest of the subject-matter itself. We have carried out experiments on each of these variables in turn.

We began by trying to assess the relative legibility of the different book-faces that are now in common use. For this the experimental plan ultimately adopted was similar to that described in the investigation on reading carried out in conjunction with Mr. B. Lewis.¹ The method then used was virtually a combination of randomization with a scheme of Latin squares; but certain minor modifications were introduced to meet the special requirements of psychological research. For the present inquiry ten groups, each consisting of 15 boys and 15 girls aged approximately 10·0 to 11·0 years, were selected by means of preliminary tests, the members being carefully matched so that the means and standard deviations of each group were approximately the same as regards both general intelligence and reading ability. Thirty short stories, each about a page in length, were constructed, and set up in 10 different type-faces—all roman—with 3 sizes for each (9-, 10-, and 11-point for the larger faces, 10-, 11-, and 12-point for the smaller). For each passage a questionnaire of 25 questions was drawn up; and the drafts for both stories and questions were tried out first of all, and where necessary amended, until they appeared to be about equal in difficulty. In the final experiment every pupil was asked to read 10 passages, one in each style of type, the different stories and the different sizes being allotted according to the randomized scheme.² The preparatory trials had shown that, after the first test had been taken, the order in which such passages were read made little difference to the accuracy of the reading. Accordingly, the main experiment started with a preliminary story, used merely to provide a certain amount of practice. A short series of supplementary experiments were made with italic type-faces; but for these the groups were somewhat smaller.

TABLE I. SPEED AND COMPREHENSION WITH DIFFERENT TYPE FACES

Type Face	Roman		Italic	
	Time (Seconds)	Comprehension (Items)	Time (Seconds)	Comprehension (Items)
Old Style (161)	96	28·0	—	—
Imprint (101)	97	29·1	113	26·9
Times New Roman (327)	102	27·9	118	25·8
Plantin (110)	105	26·8	129	25·0
Bembo (270)	106	26·5	135	23·7
Baskerville (169)	108	27·0	137	24·8
Caslon (128)	112	27·6	138	25·0
Scotch (46)	114	25·9	108	27·3
Modern Extended No. 1 (7)	116	25·8	116	26·1
Bodoni (135)	125	25·1	124	25·8

The numbers in brackets refer to the serial numbers of the Monotype Corporation. The chief differences between the type-faces used are illustrated by the specimen letters printed in the appendix (pp. 45-57).

Most investigators (cf. 22, pp. 114 and refs.) describe the size of the type used for their tests in terms of ‘points’ ($\frac{1}{16}$ in.). But the x-height of different faces of the same nominal size in points differs considerably: for example, with 10-point that of Times New Roman is 0·062 in.; that of Bembo only 0·050 in. To allow for these divergences the figures obtained with different point-sizes were weighted appropriately and then averaged, so as to reduce all to terms of the same x-height, namely, 0·060 in. (that of 11-point Imprint and Modern 7). The averages so obtained, for both speed and accuracy, are summarized in Table I.

¹ *Brit. J. Educ. Psychol.*, XVI, 1946, pp. 116-32. The reasons for the modifications are there explained in the footnotes on pp. 121 f.; cf. also *ibid.*, IX, 1939, p. 259.

² Most of our reading-passages have been set in monotype. But in our earliest experiments a good deal was either hand set or composed in linotype. In the earlier stages we also used Modern No. 1, Series 1, and Old Style, Series 2—two of the oldest monotype faces, cut in 1900 and 1901 respectively. For these we afterwards substituted Modern Extended No. 1, Series 7, Imprint, and Old Style, Series 161. Times New Roman did not become available until 1933, when *The Times* released the design for general use.

Experiments were also made with Garamond, Fournier, Ehrhardt, and Gill Sans: but for children these were found to be much inferior to the eight type-faces eventually selected.

The data was subjected to an analysis of variance in the usual way. The variance of the means of the different groups, and the variances of the means for the different passages, were statistically non-significant; the variance of the means for the different type-faces was fully significant. The differences between adjacent pairs are too small to be significant statistically; but it will be observed that the order of the type faces in all four columns shows a fair amount of agreement.

The British Association Committee recommended old faces rather than modern, and gave Caslon the preference. In our own experiments we found both Old Style and Imprint far more satisfactory than Caslon. (Old Style and Imprint may be regarded as modernized versions of Caslon, with its more peculiar features removed—notably the sprawling capitals which tend to distort the familiar word-form.) As regards roman types (i.e., the upright letters now ordinarily used for consecutive prose), Imprint appears on the whole to be the best; Plantin¹ and Times New Roman are nearly as good, although with the younger children their short ascenders and descenders seem at times to render the word-form less distinctive.²

The modern type faces were the least legible.³ As the reader will see if he compares 'n' and 'u' in (say) Garamond and Bodoni respectively, the older faces accentuate those parts that are different, while the modern faces accentuate those that are similar. With the latter, therefore, letters are far more readily confused. Legibility is still further diminished by the excessive disparity between the thick vertical strokes and the thin curves and slanting strokes: to a child who is slightly hypermetropic or astigmatic, a word like 'minimum' printed in Bodoni looks like a succession of i's, and the whole line gives the impression of a palisade. Condensed faces (such as are seen in many French reading books) are also liable to look blurred to the hypermetropic eye; on the other hand, excessively expanded faces (such as are occasionally found in American books) tend to disrupt the word form.

Some of the commoner type-faces present special difficulties to children because of the unusual shapes of certain letters. The lower serif or beak on the capital C in Bodoni, Baskerville, and italic Caslon, causes many to mistake it for G. Capital Q in Imprint and Times Roman is sometimes mistaken for O. The old-fashioned Y in italic Caslon and Baskerville puzzled many young readers. The barred italic J of Caslon, Imprint, Plantin and Baskerville was read by many children as 'f'; and the italic h of Garamond and one or two other old faces tends to be read as 'b'. In Caslon italic the extreme slope of the letters and the wide separation of many capital initials from the rest of the word also caused confusion. On the other hand, we found that, particularly with very young children, the modern face R (with its curling leg) and Q (with its tail beginning inside the counter) were more readily recognized than the corresponding old face capitals. The larger eye of the modern e makes for greater legibility: children with imperfect vision sometimes mistake a Baskerville or Caslon e for c. The modern faces have one further advantage frequently noted by teachers: the ranging numerals are said to be much easier for children (those of Scotch Roman and Times Roman appear to be easiest of all); whereas the ascending and descending numerals of the older faces occasionally produce an appreciable hesitation, particularly when the figures are grouped.⁴ Here as elsewhere, however, much depends upon the style and shapes to which the child has been accustomed. For young children, we are firmly convinced, there would be a great advantage in selecting a single legible set of letter-shapes, keeping strictly to these, and allowing no picturesque divergences. For them too, displayed material, such as titles of stories, headings to chapters, and the like, should be set, not in capitals, but in lower case with capital initials.

We attempted similar experiments with adults (chiefly students and other educated readers) confining ourselves for the most part to seven type-faces only (Imprint, Times, Baskerville,

¹ A smooth hard paper was used: otherwise, owing to its heavier impression, Plantin would have proved the most legible of all: (see section on 'Boldness').

² A fount of Times Roman with long descenders is now available. We may add that, although the long ascenders and descenders adopted by most 'modern' faces tend to increase the legibility of the isolated letters for younger children, they spoil the characteristic unity of the words for older readers.

³ Of the semi-modern type-faces, 'Century' (a type used for a popular series of school readers) appears on the whole to be the most readable. But its merits were not great enough for us to include it in our final series (see *Monotype Recorder*, XXXIV, 1935, pp. 18 f., and David Thomas, 'School Books and their Typography,' *Printing Review*, XIII, 1934, pp. 5-8).

⁴ Several of the 'old faces', e.g., Imprint and Bembo, are now provided with an alternative set of ranging figures. We believe, however, that the question has generally been oversimplified and the effect of habit usually overlooked. Certainly the descending 3 and 5 of Plantin and Imprint are easily confused. On the other hand, with lining figures 3 and 8 are confused, especially in reading small-type mathematical tables. Thus, we are inclined to think that, for tables like those of Chambers, a slightly ascending 6 and 8 would aid discrimination, especially when there is a chance of the plates getting worn. In our opinion, however, the whole subject calls for further investigation by up-to-date psychological techniques.

Bembo, Old Face, Scotch, and Modern). Unfortunately, it was impossible to plan the research as systematically as before or to test such large numbers. The results are therefore not worth reporting in any detail. With adults, we found 10-point Times Roman proved far more legible than 10-point Bembo or Caslon; but this is mainly due to the fact that with the former the x-height is much larger. When allowance is made for differences in visible size, there is, for persons of normal eyesight, virtually no difference in legibility between the commoner book faces. For older persons and for those with visual defects, type faces varying widely in the thickness of their lines and (to a less extent) those with hardly any variation at all seem the least legible. For such persons the general order of legibility appears to be much the same as for children. The chief exception is Modern No. 1 which causes far less difficulty to adults, particularly if (like Science students) they are already fairly accustomed to it.

(b) *Boldness*. For readers who are hypermetropic or astigmatic, legibility is improved by increasing the heaviness¹ of the type. But the optimal thickening is severely limited—a point which has too often been overlooked: excessive thickening tends to reduce the size of the ‘counters’ (i.e. the white inner spaces) in such letters as ‘a’ and ‘e’. A moderately bold or heavy type seems definitely preferable in books intended either for the very young or the very elderly. For the normal eye of youth there is little gain but rather the reverse.

In several type faces the boldness is achieved mainly by thickening the vertical strokes, as for instance in Times Bold (328): Times New Roman Semi-Bold (421) avoids these disproportionate differences, but the set is a little too narrow especially in the larger sizes. With children Plantin (110) owes its legibility partly to the fact that it leaves a somewhat darker impression, especially on uncoated paper: but the peculiarities of the capital C and W, and the splayed capital M, as well as the lower case j, are unsuited to the younger readers. For them the most legible fount would seem to be a semi-bold ‘Old Style,’ e.g., Monotype Old Style Antique (161)—a type design² which now seems to be seldom used for ordinary book work. For elderly readers we found Veronese (59)—one of the earliest of the machine type-faces to aim at aesthetic quality³—apparently the least tiring.

(c) *Size*. Our next problem was to investigate the influence on legibility of size. We began with Old Style Antique. However, in producing books for younger children printers and publishers still use a wide variety of type faces; and we therefore decided that norms stated in terms of one of the more widely available founts, with no marked leanings toward any exceptional characteristics either in design or in heaviness, would be more useful than norms stated in terms of a type that is now comparatively infrequent. Accordingly, after some consultation with teachers and publishers, we eventually determined to base our norms on Times New Roman.

The British Association Committee gives requirements in terms of *minimum* size, with specimens in Caslon. We found, however, that, particularly with older children, a type-face might err by being too large as well as too small.⁴ Hence we preferred to formulate our standards in terms of optimum sizes. The results⁵ of our most recent experiments are shown in Table II. If a semi-bold type is used instead, the optimum size would be slightly smaller for ages 8 to 10 and slightly larger for ages above 12. We would add that, for the very

¹ For recent studies on this point, see M. Luckiesh and F. K. Moss, ‘Boldness as a Factor in Type Design and Typography’, *J. Appl. Psychol.*, XXIV, 1940, pp. 170-83, and *id.*, ‘Criteria of Readability’, *J. Exp. Psychol.*, XXVII, 1940, pp. 256-70. The writers experimented with Memphis type of four degrees of heaviness: but the differences found were small and in our view of doubtful significance.

² The term ‘antique’ refers, not to the design, but to a particular kind of heavy face, distinguished from that called ‘clarendon’ chiefly by the treatment of the serifs and by a wider set.

³ If the reader will glance at (say) the prefaces to pocket Shakespeares published from Aldine House, he will see how surprisingly legible even the tinier founts can be. But these somewhat colourful faces are better suited to classical or poetic productions than to scientific work.

⁴ Kerr points out that the largest of the large letters should in no way approach the limits of the young reader’s area for distinct vision. In the British Association Report the largest of the specimen letters intended for beginners (who were apparently supposed to read letter by letter) was 0.16 in. high. Kerr observes that, at the ordinary reading distance, this would be about one quarter of the vertical size of the area of distinct vision. However, his estimate for this area appears to be derived from early experiments on adult vision, and greatly exaggerates the vertical span for the small child. But in any case, deductive determinations of this kind appear to us to be decidedly precarious; and from more direct estimates we believe that the maximum has commonly been overrated.

⁵ A rough notion of the effect of these requirements can be obtained by glancing at Burt’s Graded Reading Test (Test 1, *Mental and Scholastic Tests*, pp. 340-1) which is intended for children aged 4 to 14 and was based on an earlier set of norms differing but slightly from those set out above. The same type face has also been used in the Standardized Attainment Tests recently issued by the Kent Education Committee (1954).

young (aged 9 or below), the words should be well spaced out—with an em-space as a minimum instead of an en-space as a maximum: and thin spaces should not be used in books intended for children.

TABLE II. TYPOGRAPHICAL STANDARDS FOR CHILDREN'S READING BOOKS

Age	Type-face (points)	Type-body (points)	x-height (inches)	Number of Letters in a Line of 4 in.	Length of Lines (inches)	Interlinear Space (inches)	Number of Lines per Vertical 5 in.
Under 7 years	24	30	0.150	30	5	0.250	12
7-8 years	18	20	0.111	38	4	0.170	18
8-9 years	16	18	0.090	45	3½	0.150	20
9-10 years	14	15-16	0.075	52	3	0.130	24
10-12 years	12	14	0.068	58	4	0.110	28
Over 12 years	11	12	0.060	60	4½	0.100	30

In Column 4, 'letters' means lower case characters or spaces, the space between two words being counted as one 'letter'.

For adults we used 8-, 9-, 10-, 11-, 12-, and 14-point Times Roman. With this face set solid, the most legible size was 10-point with an x-height of 0.062 in.¹ Judging by the average figures, any diminution in size (even by one point) and any great increase in size (two points or more) tend to reduce legibility. Although large letters are the most legible when read singly, they by no means favour quick reading or quick comprehension when used for consecutive prose: they cause visual attention to be directed to the letters themselves rather than to the form of the words, and to single words rather than to groups or phrases: the bigger the type, the smaller the amount of reading-matter falling within the normal eye-span, and the larger the number of eye-movements and fixation-pauses.

There were, however, marked differences in optimum size from one person to another, for the most part related to differences in visual acuity. With individual readers possessing normal eyesight the effects of small changes in size were insignificant. Older persons, even with apparently normal sight, often found 11-point more legible than 10-point. The majority of students (aged 19 to 26) found 9-point equally legible. But with presbyopic readers 9-point was apt to hinder comprehension and to induce eye-strain when reading was prolonged: these effects were evident, not only in the results of the questionnaire, but also in the irregularity of the eye-movements and in the increased blinking which became obvious to the investigator as he watched the reader.

(d) *Leading*. The introduction of 'leads' (i.e. thin metal strips inserted to widen spaces between the printed lines) greatly enhances the legibility of small type. In particular, it aids the eye to pick up the right lines as it moves back from the end of one line to the beginning of the next—a point of special importance with children who are extremely prone to doubling and skipping. In the table above, the 'interlinear space' is measured from the base-line, i.e. the bottom of the non-descending letters, to the top of the non-ascending letters of the line next below. Roughly speaking, the distance should be about half as wide again as the x-height—rather more with younger children, rather less with older—rather more with wide measures, rather less with narrow, in general, say about one-thirtieth of the measure. When the type used is large on its body or has long ascenders and descenders, it is essential that the leading should show a clear separation between the two lines especially when a descender comes directly above an ascender.

In this journal three sizes of Times Roman are used for the text—10-, 9-, and 8-point, all set solid. With these we found that the introduction of one or two points of leading appreciably increased the ease of reading. (With type-faces that are smaller on their body, like Bembo or Caslon, one point appeared sufficient.) Little seems to be gained by 3-point leading. 4-point leading usually diminished legibility. Like excessive letter-size, it tends to increase the number of eye-movements and fixation pauses. Plainly, the use of generous spacing can easily be overdone, as many readers have probably felt in perusing the first editions of the works of Ruskin or Tennyson.

¹ This is roughly equivalent to 11-point Baskerville and 12-point Bembo.

(e) *Measure*. Table II indicates what we consider to be the most suitable length of line for children of varying ages. The limiting condition is a matter not so much of visible inches but rather of the number of letters. With adults our experiments were in the main restricted to reading matter set in 10-point Times Roman. With this type, measures¹ shorter than 20 ems or longer than 33 ems diminished speed and ease of reading. Very roughly, these are limits of $3\frac{1}{2}$ to $5\frac{1}{2}$ in., 55 to 80 characters and spaces, or 2 to 3 lower case alphabets.² For literary material the narrower measure is desirable (say $3\frac{1}{2}$ to 4 in.); for scientific the wider. For a scientific journal intended for highly educated readers, who of course tend to skim rather than read word by word, a measure of 5 in. seems preferable.³

With long lines of solid type the eye finds it difficult to pick up the right line in turning from the end of a given line to the beginning of the next; and large pages filled with solid-looking panels of printed matter are apt to repel all but the hardened scholar. On the other hand, short measures, particularly when the type is big, prevent the eye of the trained reader from taking in large phrases with a single fixation and from making the most of the subsidiary help given in the horizontal direction by peripheral vision. Moreover, they necessarily entail widely varying spaces between the words, and increase the number of broken words at the end of the lines—features which appreciably hinder comfortable reading.⁴

Where the reading matter requires to be read mentally word by word (as in poetry), small measures, wide interlinear spacing, and even small type with fairly broad spaces between the words, are an advantage.⁵ At the same time, small type further aids the eye to appreciate the shape of the stanza, especially where the metric structure is at all complex.

(f) *Margins*. There can be little doubt that books with excessively narrow margins are more apt to produce visual fatigue, though the diminished weight of the volume may then perhaps slightly lessen manual fatigue. Moreover, when the type-area extends nearly to the edge of the paper, the eye of the younger reader is apt to swing right off the page. With adults the effect of the broader margin would seem to be chiefly aesthetic.

To gain light on this problem we carried out a number of experiments upon readers' preferences in regard to the general imposition of the type upon the page. The results varied widely according to the subject matter of the book (literary or scientific), the size and shape of the page, the size, style, and interlinear spacing of the type, and so forth. To simplify the task we confined ourselves mainly to volumes whose pages showed proportions approximating to those of the golden section ($1 : \frac{1}{2}\{\sqrt{5}-1\}$ i.e., 1.000 : 0.618) : this covers most of the ordinary octavo sizes. Expressing the margins as percentages of the measure, the weighted average of the preferred specimens gave the following proportions (rounded for convenience) : (i) inner margin 17.5, (ii) head 22.75, (iii) outer margin 27.5, (iv) foot 32.5. These are very nearly $\frac{7}{40}$, $\frac{9}{40}$, $\frac{11}{40}$, and $\frac{13}{40}$ respectively. The total of all four, it will be observed, adds up to the size of the measure.

Let us consider how this would work out if applied to a demy octavo publication (such as Spearman's *Abilities*, Thomson's *Factorial Ability*, Burt's *Factors of the Mind*, or the journal *Mind*). The dimensions of the trimmed page would be about $5\frac{1}{2} \times 8\frac{1}{2}$ in. ; and the foregoing recommendations

¹ The 'measure' (i.e., width to which type is set on the printed page) is generally stated in terms of '12 point ems', i.e., in multiples of one-sixth of an inch : (this unit is sometimes, but not quite correctly, designated a 'pica' ; e.g., [22], p. 114).

² The last is a convenient mode of statement, since most specimen sheets give the length of the alphabets. With types of other sizes the same alphabetic rule will serve. If a large body is used (or the equivalent in lead), take the alphabet length of type corresponding to the body size : e.g., with 10-point type set with 2 point lead, take the alphabet length of the corresponding 12 point type.

In studies of legibility the influence of the width or 'set' of a type face has been almost wholly ignored. And, although we ourselves have made no direct investigation of this aspect, we believe that its importance is by no means negligible, particularly in books for children. This indeed is one of the reasons why, from a psychological standpoint, we consider it preferable to state the length of the lines in terms of characters or words rather than in ems or inches : thus for the educated reader lines of 10 to 16 words—say 13 words on an average—seem most suitable.

³ A line of 5 in. implies a page of about $7\frac{1}{2}$ in. wide, i.e., crown quarto. For books an octavo size is more convenient.

⁴ On the basis of an admirably planned series of experiments Paterson and Tinker summarize the essential results as follows : 'One may characterize the oculo-motor patterns in reading an excessively short line by saying that the number of fixations is increased, the span of perception decreased, the mean duration of fixations increased, total perception time greatly increased, though the number of regressive movements remains approximately the same. . . . An excessively long line gives major difficulty in swinging back to the beginning of successive lines' (D. G. Paterson and M. A. Tinker, 'Influence of Line Width on Eye Movements', *J. Exp. Psychol.*, XXVII 1942, pp. 574-6). Their optimum range for 10 point type (80-88 mm. or 19 to 21 ems) implies rather narrower measures than that recommended here. But otherwise our findings seem perfectly consistent with theirs.

⁵ One of us has an early edition of Tennyson's *Princess* in a long primer (roughly 10-point) with 8-point leading. Certainly the poet successfully compels his readers to read slowly !

would imply a measure of 22 ems or $3\frac{2}{3}$ in. and a depth of 38 ems or $6\frac{1}{4}$ in. (i.e. a type-area somewhat smaller than was actually adopted for the publications mentioned). With 10-point Times New Roman set on a 12-point body, each page would then contain 38 lines, i.e., about 2100 characters or 360 words. The margins would be : (i) backs, $\frac{2}{3}$ in., (ii) head $\frac{5}{8}$ in., (iii), fore-edge, 1 in., (iv) foot or 'tail', $1\frac{1}{4}$ in.¹

Roughly speaking the two side margins should together take up a third of the entire width of the page, i.e., half the measure. When the interlinear spacing is increased, all the margins should be increased. For young children the proportions should be much wider, allowing plenty of room at the bottom for the thumb and at the sides for the untrained eye to swing to and fro. For infants the line should end with the end of a phrase, leaving the margins irregular.

For highly technical works a larger page may often be desirable, e.g., royal octavo ($9\frac{1}{2} \times 6$ in.), and somewhat narrower margins can be tolerated, and indeed, in the view of most readers, would even be preferable. For a technical journal a broader page is desirable, e.g., crown quarto (10×7 in., allowing a measure of 5 in.).²

The Interaction of these Factors. In the course of all these experiments it soon became obvious that the procedure adopted by most psychological investigators, namely, studying the effects of the four or five main variables separately—size, leading, line-length, style, and heaviness of face—is quite inconclusive, as indeed the practice of every good printer should suffice to show. For example, a line of 5 inches is easier to read than one of 3 inches provided 10-point or 11-point is used : when 8-point is used, the reverse is true. 9-point type, set solid in a measure of 5 inches, is harder to read than 10-point : but, set with 2-point leading, it is just as easy, at least for the average adult ; and it is almost as easy in a measure of 3 inches if only 1-point leading is used. 3-point leading seems disadvantageous with ordinary faces ; but with comparatively heavy type, and a face that is wide rather than condensed,³ it is of definite assistance to children.

Practical Corollaries. In summarizing the foregoing results, it may be of interest to consider them more particularly in relation to journals such as those published by the British Psychological Society. It should again be emphasised that our conclusions are themselves merely tentative, and require further verification : other factors besides those we have studied here may conceivably have an overriding importance.

Were we guided by the data so far adduced, we should be tempted to infer that the length of line ($5\frac{1}{2}$ in.) which is adopted for the *British Journal of Psychology* (i.e., what until recently was called the 'General Section') is, if anything, rather too wide for the size of type employed ; that adopted for the present journal (5 in.) is satisfactory for academic readers ; that adopted for the *British Journal of Educational Psychology* ($4\frac{3}{4}$ in.) is well suited for a journal of a slightly more popular kind ; while the short lines ($2\frac{3}{4}$ in.) recently introduced by the *British Journal of Medical Psychology*, which is set with two columns on a page, are likely to diminish speed of reading, though they may possess other advantages of their own. Much, however, must depend on the style of printing to which the reader is accustomed. And in books and periodicals dealing with advanced mathematics the more elaborate algebraic equations would of necessity be badly broken up if set in columns of $2\frac{3}{4}$ in. ; indeed, it was for this reason that the editors of this journal at the very outset chose a rather wide measure.

¹ It was noteworthy that elderly readers (including the oldest of the present writers) strongly preferred a much larger head margin no doubt as a result of preferences acquired when such margins were more fashionable. This would incidentally keep the proportions of the printed panel, as well as those of the page, near to the golden section.

In works on book production it is often stated that diagonals uniting the corners of the page should also pass through the corners of the type area ; that the inner margin should be half the outer ; and that the proportions should be approximately $1\frac{1}{2}$, 2, 3, and 4. This mode of imposition satisfied few of our readers ; and it was frequently complained that the inner margins were so narrow that, with a thick and tightly bound volume, the words nearest the inner edge were hard to read. It may be noted that the proportions suggested in the text imply that the printed area will be no more than about 50 per cent. of the total area of the page. The war-time economy regulations required that the type area should fill at least 58 per cent.

² The proportions preferred for the margins of a crown quarto page (the size of the Society's journals) were much the same as those cited above, with slightly narrower head and bottom margins. They fall midway between those adopted by the Cambridge Press for the *Brit. J. Psychol.* before and after 1942 (namely, 1 in., 1.4 in., 1.6 in., and 1.9 in. with a measure of 4.4 in., giving a type area of 30 sq. in., and 0.6 in., 0.9 in., 1.1 in., 1.2 in., with a measure of 5.3 in., giving a type area of 42 sq. in.). Note that in all these specifications the running headlines and folios are not counted as part of the type area.

³ Times New Roman (327) has a rather narrow set : the width of the lower case roman alphabet, set in 8-point (x-height 0.052 in.) is only 105 points, whereas that of Perpetua 11-point, which has practically the same x-height, is 118 points. 11-point Imprint and Modern 7 (both with an x-height of 0.060 in.) have an alphabet width of 128 and 135. 10-point Times Roman with a larger x-height (0.062 in.) has an alphabet width of only 124 : this condensation makes it, in our view, unsuited to children under the age of 10, and caused a number of our readers to deprecate its use for literary publications.

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For mathematical work the Committee of the Royal Society¹ selected three type-faces—Imprint, Times New Roman, and Modern 7. For books we are inclined to favour 11-point Imprint (large face) on a 12-point body set in a measure of about 23 ems (3.83 in.), or 25 to 28 ems if there are numerous equations. For periodicals this face seems a little too large, while the 10-point seems a little too small; and a larger measure would certainly be desirable. On the whole, the most favourable type for such publications appears to be 10-point Times Roman with long descenders and with 1-point leading: (2-point leading if the older version, with short descenders, is used). For subsidiary matter, 9-point with 1 point leading, which is almost equally legible, might be substituted. No serious difficulty seemed to be experienced with short footnotes of 8-point, even when set solid, particularly when they deal mainly with references or somewhat specialized comments. But a good many readers find it hard to cope with 8-point matter running to lines of 5 inches when continued for more than half a page.² On all these points we should welcome comments from our readers.

Introspections. In the course of all these experiments, especially when our examinees were adults, we tried to elicit comments and introspections. It was most instructive to observe how often the subjective impressions of the readers failed to correspond with their actual efficiency.

Certain readers, for example, reported that they found 12-point type more legible than 10-point, others that they found 9-point type quite as legible as 10-point type, when their actual performances demonstrated beyond question that they were wholly mistaken. Often they ascribed to the design of the type effects that were really due to the size of the type or to the leading. The spacing between the lines and the length of the measure produces illusory estimates of the relative size of the print: with both 9- and 10-point type, readers who found that the change from solid type to 2-point leading improved their accuracy or speed frequently explained that they found "the large type much easier" when the size of the face remain unaltered. Thus, as Mrs. Beatrice Warde has rightly observed, "What the book critic calls readability is not a synonym for what the optician calls legibility."³ Nearly all tended to read with greater facility the kind of types that they preferred, and were inclined to confuse intrinsic legibility with their private aesthetic preferences. As we have seen, preference depends largely upon custom; and throughout it seemed evident that *almost everyone reads most easily matter set up in the style and size to which they have become habituated.*

III. AESTHETIC PREFERENCES AND THE CLASSIFICATION OF TYPE FACES

The Study of Preferences. On looking at recent scientific publications both in this country and America, one is tempted to echo a remark of Bernard Shaw's: "It is a mistake to think that the modern author is insensitive to the beauty of a finely designed and well printed page: he positively hates it." No doubt war-time regulations, the increasing need for economy, and, in technical subjects, the fact that the better designed founts are deficient in 'mathematical sorts' may be in part responsible. But authors and readers are themselves largely to blame. The scientific writer is apt to declare that "print is required for use not for ornament: its function is to be legible, not to look beautiful". Scientific readers, so far as our results can be trusted, vary much more widely than others in typographical taste and interests—the least sensitive usually predominating. And both author and reader are quite content to leave such matters to the printer or publisher.

The best publishers and typographers are fully alive to the importance of psychological factors. They recognize, as Oliver Simon puts it, that "there are aesthetic considerations prompting people to prefer one type rather than another, which are closely linked with the emotions and difficult to define precisely" [21, p. 11]. In work on book production and in the journals of the trade there has of late been much discussion about the artistic qualities of different type-faces; and, from the earliest days of printing, sculptors, architects, painters, and engravers have applied their skill to the designing of type. Yet hardly any objective or systematic research has been undertaken on the psychological questions involved. The psychologist, though he has studied legibility and made sporadic investigations in almost every other branch of art both pure and applied, has remained singularly uninterested

¹ See *Notes on the Choice of Type Faces for Scientific Periodicals* (1950) drawn up under the Chairmanship of Dr. S. Zuckerman by the Consultative Committee for Co-operation with Printing Organizations.

² Quite independently, Mrs. Beatrice Warde (of the Monotype Corporation) suggested that the footnotes in the Journal might be divided into two columns. The Editor would like to express his indebtedness to Mrs. Warde for her kindness in responding to various questions about the printing of the Journal and for her valuable advice.

³ *Monotype Recorder*, XXXII (1933), no. 1.

in the aesthetic aspects of printing—a form that silently confronts him every day of his life. The problems, moreover, are not without their practical importance. This is perhaps most obvious in the psychology of advertising. Here the readers' reactions, whether conscious or unconscious, towards the style of printing adopted by the advertiser may defeat the entire purpose of the advertisement. Yet once again, though numerous experiments have been carried out on visibility and display, hardly any attempt has been made to discover what particular qualities make different kinds of type-faces attractive or otherwise to different kinds of public.¹

Methods. In planning a tentative inquiry into the more obvious problems, we have followed much the same general procedure as was used by one of us in previous investigations on personal taste in literature, art, and music. We collected examples of all the commonest type-faces now in regular use, and then submitted them to a number of persons of both sexes, with the request that they would arrange the various specimens in order of preference. Nothing was said about the differences being aesthetic. Indeed, it was part of our problem to discover how far, if at all, the judgments were comparable with other modes of aesthetic appreciation. As in our work with pictorial tests and with projective tests such as the Rorschach, we used two methods of factor analysis—'correlating persons' and 'correlating items'.

(a) *Correlations between Persons.* We began with what is commonly called 'P-technique', i.e. correlating the rankings submitted by the several individuals and then factorizing the correlation table by simple summation. The method was first tried with twenty persons selected to represent different classes of reader.

Their rankings revealed a moderately large 'general factor for persons', accounting for nearly 41 per cent. of the total variance. Such a factor implies the presence of a common tendency underlying the different orders; what is its precise nature we shall consider in a moment. The second factor was bipolar, and contributed 13 per cent. to the total variance. It subdivided the entire group of persons into two subgroups: their factor measurements indicated that, with few exceptions, those in one subgroup tended to prefer 'old' faces, while those in the other preferred 'modern'. However, a sample of only twenty persons is scarcely sufficient to establish such a classification with any finality. Several smaller factors were also discernible, each contributing about 8 to 12 per cent. to the total variance: for the most part they appeared to relate to such influences as age, eyesight, and habitual type of reading.

Introspections. All our subjects were asked to give reasons for their preferences. With typographical material the replies seem far less self-conscious—far less influenced by the natural desire to show up well, which so often impairs the sincerity of the responses to tests of pictorial taste or personality. Yet the content of the remarks is so illuminating that the whole procedure almost takes the character of a camouflaged 'projective test'. Only one of our critics had any technical knowledge of typographical differences; but many of them, particularly the book-lovers, seemed sensitive to what one of them called the 'atmosphere' set up by the type adopted.

The reasons offered could be readily classified into much the same psychological categories as were reached in our previous tests with other kinds of aesthetic material.² This will be evident from the extracts given in the appendix, but may be briefly illustrated here.

(a) *Subjective.* 1. *Associative.* (Of Modern 7 and Bodoni): "I have always disliked that kind of type because it reminds me of the print used in the French books we were compelled to read at Lausanne—the most hateful time of my life." (Of Caslon): "It seems to bring back memories of 'ye good olde days'—reading 18th century editions of Swift and Defoe in my father's library." (Of Perpetua italic): "It reminds me of inscriptions on tombstones or memorial tablets in a church." (Of Modern 7): "That for me is the only proper type for mathematical work, probably because I've always seen it in that kind of type." "With types it's much the same as with the place you live in or the author you are reading: they're all so much more interesting when you know something about their history."

¹ At the National Institute of Industrial Psychology, nearly twenty-five years ago, one of us took part in a research on the letter-press to be used in the advertisements of a well known firm of drug manufacturers. The differences in apparent effectiveness were unexpectedly wide. Still more striking are the results we have obtained on repeating the same experiment with a post war group. Though the data so far available are somewhat limited, it is difficult to avoid the conclusion that in the commercial world taste and fashion change far more rapidly and erratically than in the world of literature or journalism, and that on the whole they have markedly improved, while in the field of psychology they have definitely declined.

² See C. Burt [15], pp. 280-88; cf. also the classification of types based by Bullough and others on introspective comments explaining colour-preferences and the like: E. Bullough, *Brit. J. Psychol.*, II, 1907, pp. 111-23; C. W. Valentine, *The Experimental Psychology of Beauty* (1919).

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2. *Emotional.* (Of Bodoni): "It seems to prick and dazzle. Horrible" (Of Caslon): "Restful and soothing." "Irritating! Those italics make me want to put them straight, like pictures hanging crooked on a wall." (Of Garamond italic with its different angles): "It makes me giddy to read it."

3. *Anthropomorphic.* "A type should have an individual personality: that's why these (Caslon and Garamond) go at the top." (Of Bodoni): "Cold, stiff, and rigid, like a row of black shirts on parade." "Intellectual." "Introverted." (Of Caslon): "Homely, unassuming." (Of Fournier): "Whimsical." (Of Baskerville): "Genteel." (Of Perpetua): "Aristocratic." (A general remark): "A type should have no personality of its own: you expect handwriting to reveal something of the writer's character, but a printing machine has no character to reveal. Now these types seem to be saying 'Look at me; aren't I ingenious [Baskerville caps]? Aren't I dignified [Bodoni]? Aren't I quaintly old-fashioned [Caslon]? Each is trying to express itself when it ought to be expressing the author's meaning."

(b) *Objective.* 1. *Intuitive.* (Of Bodoni): "It gives you a general impression of an orderly formal scheme—straight verticals on a straight horizontal, everything correctly fashioned and everything correctly finished." (Of Caslon): "I placed it first, not for any particular features that I can single out, but for its general look—its Gestalt-quality, if you like: it forms just the right kind of pattern made of just the right kind of shapes." (Of Perpetua): "Every letter strikes you at once as well-proportioned, like the columns, doors, and windows in an Adam façade."

2(a). *Rationalizations.* "I'm an arrant functionalist: to me a letter looks well when it's doing its job well—no frills or fancy touches." (Of Scotch Roman): "Letters to be printed with moveable types, instead of written by hand, should be all of the same size¹; these come nearest of those you have shown me. On the other hand, in this passage (Times Roman) the S and the J are far too narrow; they should be the same breadth as the U; and the W is too broad—it would fit better if the strokes were crossed like that" (the Bodoni W). (A general remark): "In my view, the principle of parsimony requires that letters should be constructed of a minimum equipment of lines: three kinds of straight strokes—vertical, horizontal, oblique, and two kinds of circle—full size in O and Q, and half size in S and B, with both halves exactly equal. Evidently, then, letters like S and B should be exactly half the width of O. N should be a perfect square; and letters like E and F exactly half the width of N. E should be two small squares—cross strokes all equal.² This (Centaur) comes closest to my own ideal. The more they violate these principles, the lower the types go in my list. The proper way to judge them would be to measure their dimensions under the microscope."

Most of our readers sought to judge all type faces by the same fundamental criterion, differing from one reader to another. There were, however, a few exceptions. Several of the more critical asked if they could alter their rank according to the subject matter for which the type was to be used. Four insisted that it was impossible to suppose that one and the same rank-order would hold for every kind of publication. 'Old' faces and ornamental details (like the swash capitals in Baskerville italic, or the unusual k, z, and Q in Garamond) appealed to two readers as suitable for poetry or historical romances, but were pronounced quite inappropriate for a daily paper or a scientific journal. Three remarked that they liked the reprint of a classic to be set in a style suggestive of its period. One put the principle still more explicitly: "I should like a plain machine-made face for scientific books and articles, a slightly more artistic style for what they call *belles-lettres*, a decorative type for imaginative prose, and a slightly archaic form for the older writers or stories of bygone days. . . . I should hate to see Pater or Malory set up in this type (Bodoni), or Kelly's *Statistics* in either of those (Perpetua and Garamond). There's nothing intrinsically bad about any of them. Aptness is my only criterion."

Nevertheless, an explicit recognition of these different functions was comparatively rare, even among our more literary readers. It was, indeed, surprising to note how few appeared in any degree typographically conscious. Many started straightaway with some deprecatory remark, to the effect that "all kinds of type look much the same to me". Yet, after a few moments' scrutiny, about one in three would become either wholesale critics or ardent admirers of this or that set of features in some particular group of faces.

(b) *Correlations between Type Faces.* To investigate the nature of these differential preferences we compiled a special set of test-material consisting of extracts cut from printers'

¹ The idea that every printed letter should fit into a rectangle of the same size and shape was a principle tacitly or explicitly adopted by many of our readers. Here possibly the influence of the typewriter may be discerned.

² It was surprising to discover that even our psychological critics were quite unfamiliar with the curious optical illusion whereby the top halves of the S, 8, etc., appear much larger than they are (as may be readily seen on turning the page upside down). If, therefore (as this reader demands), the letter S was mechanically constructed so that the top curve had exactly the same size as the lower, the top curve would, curiously enough, look very much larger.

specimen books, keeping so far as possible to the same or similar prose passages for all type-faces, but including in every instance a complete alphabet, in upper and lower case, both roman and italic. We selected type with an x-height of 0.062 in. or thereabouts (10-point for the larger faces, e.g., Times New Roman, 11-point for the smaller, e.g. Imprint and Modern 7).¹ These were submitted to 93 judges—teachers, students, University lecturers, and educated readers of the commercial or industrial classes. Most of them also took part in short tests of pictorial and of literary appreciation: (those described by Dewar and Williams [17, 18] were used).

A group of nearly a hundred is too large for P-technique. We therefore decided to 'correlate tests' rather than persons. For this purpose we first converted the rank orders into normal deviates; these were then reduced to deviations about the average for each type-face. Finally, we calculated all the inter-correlations between the different type faces, and factorized the table so obtained. It shows two peculiarities which have occurred—though not with any frequency—in other investigations on personal preferences (e.g., in a study of pictorial preferences by Sybil Crane): (i) the largest factor is not a general factor with positive saturations throughout, but bipolar²; (ii) after the general and first bipolar have been removed, the presence of residual submatrices with figures approximating to zero indicates the presence not of further bipolars, but of group factors. The final set of factor saturations was obtained in the usual way by arithmetical rotation. The results are set out in Table III.

In many respects, as will be seen, though not in all, the classification indicated by the pattern of signs resembles the broad, semi-historical classification adopted by most books on typography. To secure further light on the reasons for the divergences and similarities, we endeavoured to secure introspections, particularly from typical representatives of the more dogmatic critics. Relying mainly on these two lines of approach—quantitative and qualitative—we may provisionally put forward the following interpretation of the more conspicuous factors.

I. There is first a small general factor which here accounts for only 3 per cent. of the variance. More than half its saturations are devoid of statistical significance. Evidently the factor simply indicates that the more general differences between the type-faces were not completely abolished by taking an ordinary unweighted average when the rank-orders reduced to deviations.

II. The largest factor of all is a bipolar factor marking the contrast between (A) *Old Face* types and (B) so-called *Modern Faces*. Two of the specimens in our series—Baskerville and Times New Roman—had saturations which, though positive, were statistically non-significant.

III. After the general and first bipolar factors had been removed, the table of residuals, when appropriately arranged, showed four square submatrices containing fairly large figures, while the rest of the figures were nearly all non-significant. To fit this pattern four broad group factors were obviously required. Of these (A1) the first classifies together a set of 'old' type faces modelled chiefly on Italian or French designs: (two smaller group factors distinguish the two). I shall call this group Continental old faces. (A2) The second includes all the British old faces. The other two factors subdivide the 'modern' faces. And once again the main division is into (B1) Continental and (B2) British. Those who are interested in the details of this classification will find them discussed in the Appendix.

Implications of the Factorial Results. We do not suggest that these statistical results make any new contribution to what we may call historical or comparative typography.³ Their implications are of psychological rather than typographical interest. Supplemented by the introspective comments and biological details obtained from our various readers, the data as a whole throw considerable light on the psychological nature and the apparent causes of the varying responses which different type faces excited. There are two main questions.

¹ This decision eliminates one factor that appeared in our first exploratory studies. Certain sizes are undoubtedly more favourable to certain type-faces. Thus, Imprint, Plantin, and Times New Roman seem most effective in medium sizes: Caslon, Garamond, and Centaur show up best in larger sizes.

Since this is itself merely a preliminary inquiry, several important conditions had to be ignored. Perhaps the most important is that of paper and ink. Half-tone blocks, such as are required for many scientific works, need glossy paper; and on these types like Caslon or Garamond would be quite unsatisfactory, whereas Bodoni looks well.

² For a discussion of correlation matrices in which the largest factor is a bipolar, not a general, factor, see P. Slater and C. Burt, this *Journal*, IV, 1951, pp. 9-20.

³ In theory the saturations should indicate which particular type face is most representative of the family to which it belongs. But the data are too slender for much importance to be attached to these minor differences.

TABLE III. SATURATION COEFFICIENTS FOR TYPE FACES

TYPES	FACTORS							
	General	Old-Mod.	Cont.	Brit.	Ital.	Fr.	Cont.	Brit.
A. Old Face								
1. Continental								
<i>a. Italian</i>								
Bembo	+·173	+·746	+·342	—·062	+·433	—·063	—·084	—·034
Veronese	+·106	+·318	+·182	+·165	+·226	+·037	—·033	+·093
Centaur	+·127	+·443	+·217	+·144	+·271	—·042	+·096	+·116
<i>b. French</i>								
Garamond	+·230	+·732	+·304	—·058	—·024	+·446	—·028	—·045
Granjon	+·204	+·728	+·295	+·095	—·052	+·424	+·106	—·069
Fournier	+·191	+·581	+·342	—·107	+·067	+·519	—·090	—·167
Plantin	+·212	+·465	+·239	+·151	+·105	+·350	+·152	+·132
Ehrhardt	+·095	+·403	+·378	—·083	—·043	+·285	—·047	—·144
2. British								
Caslon	+·148	+·714	—·113	+·536	+·040	—·031	—·079	+·030
Baskerville	+·173	+·170	+·145	+·443	—·067	+·073	+·181	+·078
Imprint	+·184	+·429	—·132	+·515	—·031	—·045	—·075	—·065
Old Style	+·165	+·357	+·107	+·369	+·071	+·062	+·036	—·081
Times New Roman	+·081	+·187	—·083	+·270	+·056	—·058	—·041	+·121
B. Modern Face								
1. Continental								
Bodoni	+·219	—·781	+·179	—·121	+·033	+·054	+·534	+·059
Didot	+·175	—·660	—·123	—·032	—·051	+·167	+·373	—·084
Walbaum	+·161	—·636	+·160	—·045	+·046	—·053	+·367	—·022
2. British								
Bell	+·102	—·324	—·107	+·118	+·054	—·092	—·058	+·480
Scotch Roman	+·346	—·542	+·131	—·064	+·012	+·129	—·102	+·435
Modern 7	+·364	—·715	—·096	—·086	—·038	+·151	+·085	+·323
Contrib. to Variance (per cent.)	2·7	30·4	6·8	4·2	1·9	5·1	3·4	3·5

Figures in Bold Type are statistically significant.

First, what determines the *general* order of the type faces—their aesthetic quality, their legibility, or perhaps some other typographical characteristic? Secondly, what determines the *individual* differences—aesthetic appreciation, visual acuity, or perhaps some kind of temperamental characteristic?

General Order. The first factor obtained with P-technique may be regarded as a general factor for 'typographical taste'. The factor saturations for persons can therefore be correlated with the factor measurements for 'general aesthetic taste', based on the supplementary tests of pictorial and literary appreciation. The correlation is moderately high, 0·63. This provides a provisional answer to one of our questions. So far as these results go, we may fairly conclude that the differences between type faces on which these preferential judgements are based are largely, though not perhaps wholly, *aesthetic* differences.

Orders for Main Group and Subgroups. With P-technique the factor measurements for test-items give a weighted order of aesthetic merit for the type faces used. It will, however, be more instructive to examine the orders obtained in our second set of experiments, since these were based on a far larger sample of persons.

In Table IV we give the averages of the individual rankings for both roman and italic fonts. In addition it seemed advisable to separate our readers into two main groups according to their interests or previous education: for convenience we may call them the 'literary' and the 'scientific' groups respectively. The rankings have been averaged for each group separately; and it will be seen that they reveal suggestive differences. In the table the various type faces have been arranged according to the average preference for *roman*

counts, since this would seem to provide the best all-purposes order. The weighted order given by the general factor for persons is almost identical with the average ranking given by the 'literary' group.

TABLE IV. PREFERENCES FOR DIFFERENT TYPE FACES

Type	Roman			Italic			Combined Total
	Literary group	Scientific group	Total	Literary group	Scientific group	Total	
Imprint (101)	1	6	1	3	5	3	1
Times New Roman (327)	7	2	2	8	7	6	2
Bembo (270)	3	9	3	2	10	4	4
Plantin (110)	2	13	4	7	6	5	5
Baskerville (169)	11	5	5	11	4	9	7
Modern (7)	15	1	6	4	1	1	3
Caslon (128)	6	12	7	6	8	8	8
Bell (341)	13	4	8	10	3	7	9
Scotch Roman (46)	16	3	9	5	2	2	6
Granjon (Linotype)	8	14	10	13	16	14	11
Centaur (252)	4	18	11	1	13	10	10
Veronese (59)	5	19	12	12	12	13	13
Garamond (156)	9	17	13	9	11	11	12
Fournier (185)	10	16	14	15	15	15	15
Old Style (2)	14	11	15	16	9	12	14
Ehrhardt (453)	12	15	16	14	19	16	16
Didot (520)	17	8	17	17	18	19	17
Walbaum (374)	18	7	18	18	17	18	18
Bodoni (135)	19	10	19	19	14	17	19

The Bipolar Factor. The second factor obtained with P-technique, it will be remembered, was a bipolar factor, distinguishing those who prefer old faces from those who prefer modern ; and, in accordance with the so-called 'reciprocity principle', the first bipolar factor obtained with R-technique is, here as elsewhere, virtually the same as the first bipolar factor already obtained with P-technique. The former—those who (according to the factor measurements) preferred old faces—turn out to be, with few exceptions, students or lecturers in the Faculty of arts ; the latter—those who preferred modern faces—include most of the regular readers of scientific or mathematical works, a small proportion of the 'literary group', and the large majority of the non-academic (i.e., commercial or industrial) readers. In these cases, therefore, the individual deviations from the general order of preference appear to be in part at least an effect of habituation ; and the presence of this large bipolar factor implies, or at any rate is consistent with, the view that different kinds of type are suited to different kinds of job.

There were, however, a number of sufficiently striking exceptions to indicate that familiarity and habit are by no means the only influences. Once again, the results of our supplementary tests are instructive. They indicate that a preference for the older type faces is associated with what I have loosely called 'romantic' tendencies in other forms of artistic appreciation, while the preference for modern type faces is associated with a 'classical' taste¹: there is in fact a correlation of .43 between the two sets of factor measurements.

Legibility and Preferences. For any given type face and any given person it is possible, by the methods described in the foregoing sections, to derive two distinct measures—(i) for legibility or rather ease of reading (obtained by combining the assessments for speed and accuracy) and (ii) for aesthetic preference (obtained by converting ranks into standard

¹ Cf. [17], p. 275, [18], pp. 298 f. In these earlier researches evidence was obtained which indicated that 'romantic' and 'classical' preferences were in some degree dependent on temperamental differences. Even if this were also true of typographical preferences (and on this we had no direct information), it would not follow that the typographical preferences were *directly* affected by temperamental differences: the differences, for example, might conceivably have influenced the choice of academic subjects.

measure). Thus for each separate fount we can compute a coefficient of correlation showing how far, if at all, these reactions tend to go together. For each of the roman types in our list the correlations were positive and (with one exception) significant: they ranged from .23 for Times New Roman to .47 for Modern 7.

To secure further evidence on the significance of this relation, Mr. Cooper constructed a Snellen test-chart with Modern 7 letters, and tested the visual acuity of each available reader at a distance of 6 metres. The correlations for visual acuity were .68 with ease of reading and .36 with preference. Eliminating the effects of differing visual acuity by the usual statistical procedure, we obtained a partial correlation between ease of reading and preference amounting to .33—fully significant with the number tested (53). Taken in conjunction with introspective evidence and other observational data, the result strongly supports the view that in practice legibility is not merely a matter of the size and shape of the black marks on the white paper or of the physiological efficiency of the eye: there is also what may be called (in the fashionable phrase) a 'psychosomatic' influence at work: printed matter seems more legible, and reading becomes more accurate and quick, when the material is set in a type which the reader, perhaps without realizing it, finds aesthetically pleasing. The reader, of course, rationalizing his impressions, puts it the other way round.

Supplementary Factors. As we have seen, the remaining factors group the type-faces into families and indicate how far their special peculiarities harmonize with one another, and influence, in varying degrees, the preferences of individual readers. It would seem that, just as the style of type evolved by different nations or by different epochs reflects their cultural characteristics, so the preferences of our readers are themselves related, often in a somewhat complex and indirect fashion, to their more specific interests and cultural attitudes. Such influences are particularly obvious in the case of those outstanding individuals who in the past have sought to make a contribution to the theory or practice of typography. How far it is true of ordinary individuals further research alone can prove.

Implications for Psychology and Education. It would scarcely be appropriate here to enlarge on the corollaries that might be drawn for the psychologist or for the educationist and teacher. Two points, however, deserve brief mention. On comparing the results obtained in our more recent experiments with those obtained by one of us some thirty years ago, we have been struck by the marked changes in typographic preferences that have taken place during the intervening period; and this has brought home to us the need, and the possibility, of extending such investigations in the temporal or time-dimension by using what the factorist would probably call 'O-technique'. Indeed, a psychological study of the gradual development of taste and style during the four hundred years that have elapsed from the time of Gutenberg and Jenson to the present day might well provide a simple and instructive contribution to what has been called, perhaps a little ambitiously, the 'psychology of history'.

At the same time we venture to suggest that those who hold that "a more prominent place in the curricula for boys and girls should be assigned to aesthetic subjects and developing a capacity for the appreciation of art and industrial design"¹ might legitimately include in their efforts the appreciation of good craftsmanship in typography, in printing, and in the production of books. "A good piece of lettering" (it has been said) "is as beautiful a thing to see as any sculpture or painted picture."² And the work we have observed in some of the L.C.C. Schools of Arts and Crafts shows what can be achieved in this direction.³

IV. SUMMARY AND CONCLUSIONS

1. By means of tests of accuracy and speed, supplemented by observations of eye-movements, blinking, and other symptoms of eye-strain, an attempt has been made to determine the relative legibility of different styles of printing. The chief novelties in the experiment were the inclusion of newer type-faces issued during recent years and the application of the crucial tests after a period of preliminary reading to permit fatigue or adaptation.

2. It was found that the different characteristics—size, design, boldness of type, width of measure, of margins, and of interlinear spacing—all influence and interact with each other,

¹ Report of the Consultative Committee of the Board of Education on *Secondary Education*, p. 171.

² Eric Gill, *An Essay on Typography*, p. 22.

³ It may be added that the first edition of Burt's *Causes and Treatment of Backwardness* was set up, printed, and bound by boys in one of the schools of the National Children's Home.

so that assessments obtained by varying just one characteristic in isolation may at times be highly misleading. Revised norms for reading books have been computed for children of different ages, together with an indication of the most suitable measures and leading. On the whole, Old Style Antique appeared most appropriate for children under 12, and Imprint, Plantin, or Times New Roman for those over 12. With adult readers enjoying normal vision wide variations in design, size, or measure seemed permissible without greatly affecting efficiency of reading. Type having an x-height of about 0.060 in. (e.g. 10-point Times New Roman or 11-point Imprint or Modern 7), with 2-point leading (or 1-point with type small on its body) and a measure of 20 to 33 ems, proved to be most satisfactory for general purposes. Slightly wider measures and somewhat narrower margins seemed preferable for technical as contrasted with literary or popular publications.

3. The application of the methods already used by psychologists in research on other forms of artistic appreciation—ranking of items and a factorial study of the results—furnished an independent classification of type-faces similar to what may be called the historical classification, but differing suggestively in minor details. This psychological classification of type faces implies a corresponding classification of persons according to their distinctive preferences; and the factor measurements showed significant correlations with the type of aesthetic appreciation found with other test-material. Partial correlations indicate that apparent legibility may itself be strongly influenced by half-unconscious preferences.

4. The introspective data obtained during our experiments on typographical preferences disclose a highly complex motivation—the customary reading and the cultural interests of the reader playing an unexpectedly important role. The reasons offered by our subjects in explaining their likes or dislikes reveal much the same motivational types as have been noted by Bullough and others in their work on the appreciation of colours, pictures, and musical chords; and the content of the responses often showed a close resemblance to those obtained from projective tests with inkblots or geometrical designs.

5. The conclusions reached in this preliminary report must be regarded as provisional only. The study of preferences for different styles of printing appears to be an unduly neglected branch of the psychology of industrial design, possessing considerable practical importance for the printer and advertiser and much theoretical interest for the psychologist. Numerous incidental problems were encountered in the course of our experiments that call urgently for more intensive research.

APPENDIX

THE CHARACTERISTICS OF THE COMMONER TYPE FACES: READERS' COMMENTS AND HISTORICAL NOTES

Modern Developments in Printing. As reported in our previous issue, the Council of the British Psychological Society has decided to refer the choice of type-faces for its various publications to the new Publications Committee. If, however, such discussions are to be fruitful, it is plainly essential that those concerned should know what type faces are now available and what are their specific characteristics.¹ We know of no short publication giving this information in a compact and non-

¹ There is, of course, a prior issue. Many members of the Society hold that, in order to preserve continuity, there should be *no* change in the type or format of any journal. Others believe that there should be one type and format for *all* publications of the same society. It will be observed that on both these issues we ourselves take the opposite view. We may note that, in response to our appeal for the views of readers and members, several have complained that (if we may quote one correspondent) 'in spite of the striking advances made in British printing during the last 20 or 30 years, most of the Society's journals are still printed in the same type and style that they adopted before the first world war'. The medical journal, it may be noted, changed the type-face and the printed area in the middle of Vol XIX (1943), though the editor states that he desired to make the changes 10 years earlier. *Psychometrika* has quite recently changed its style of printing.

We ourselves are particularly indebted to the generosity of the Monotype Corporation, of Linotype, Ltd., of Intertype, Ltd., and of Messrs. Stephenson Blake (Caslon Letter Foundry) for presenting us with specimen books, specimen sheets, etc., usually available only to the trade. Examples showing the more distinctive letter-forms in the various type faces that we used will be found on p. 57. The terminology used in describing them is based on that proposed by Mr. Joseph Thorp [12]. We have also to thank Mr. David Thomas (Typographical Consultant to the Publications Department of University College) who was good enough to read these pages in proof, and suggest several important corrections.

technical form. The same want has been felt in discussing the selection of type for children's books and for verbal tests; and several teachers, psychologists, and education officials have asked for some such synopsis. A detailed enumeration of distinctive peculiarities will have little interest for the ordinary reader; but it is indispensable for our purpose, since (as we have frequently observed) an unsuitable eccentricity in one or two letters is apt to be overlooked until the type face has been chosen and the material actually set up. In citing examples, we have, so far as possible, tried to name books and periodicals which would be familiar to psychological and educational readers, and at the same time illustrate the use of the italic as well as the roman forms. Those who have taken part in our experiments and discussions have frequently inquired about the origins of the various designs, and of the names by which they are known: and consequently we have included a few brief notes on the sources of the commoner faces. Indeed, without some knowledge of their history, and of the conditions under which they were produced, it is difficult to appreciate the nature and appropriate functions of the different types.

Origins. Printing is an art in which, for both historical and technical reasons, the personal element and the mechanical are blended as they are in no other. This double character, as may be seen from the introspections of our subjects, is largely responsible for the conflicting criteria to which they variously appeal, and for the unique and complex problems in aesthetic psychology which the study of printing presents. The production of books was the earliest industry to which methods of mechanical standardization and mass production were applied.¹ The idea of using movable types was apparently due to Dutch woodcutters. The special invention of Johann Gensfleisch ('Gooseflesh', known as Gutenberg, from the village from which his family came) was the punching of metal matrices and the use of adjustable moulds in which movable types could be cast in large numbers. For the results to be intelligible to his readers the printer had necessarily to imitate the handwritten letters with which they were already familiar. Gutenberg (1454), like Caxton after him (1474), printed in 'Gothic'. What today we call 'roman type' was evolved in Italy, between 1465 and 1470, from a curious combination of Roman inscriptional majuscules, dating from the period of Trajan's column (2nd century, A.D.), and a Renaissance revival of the Carolingian minuscules.² As a result the shapes of our modern capitals are derived, not from the attractive curved uncials, developed by scribes during the fourth and fifth centuries, but from square geometrical forms incised on stone with a chisel; on the other hand, the smaller characters of our 'lower case' still preserve much of the qualities of handwritten letters, notably the oblique thickening produced by the slit and slightly canted nib of a reed or quill.³

A. Old Faces. The types commonly grouped under the phrase 'Old Face' are characterized (i) by light 'colour' (in the printer's sense), (ii) by comparatively slight differences between thick and thin strokes, (iii) by bracketed and sloping serifs, (iv) by the oblique or 'biased' shading which is characteristic of pen work, and (v) by figures which do not range on the line.⁴

As noted above, those of our readers who obtained positive factor measurements for Bipolar II (mainly readers in our 'literary group') preferred types belonging to this family. It was here that the conflict between the two rival criteria became most evident. This is clearly discernible in some of the introspective comments quoted above. The following are still more pertinent. "This style of printing (Modern 7) seems lifeless and machine-made; the others (Bembo and Caslon) look as though they had been drawn by a human hand." "Those types (Bodoni and Scotch Roman) look too geometrical; a book is a work of literature—of art; and the type should have something of the organic grace of a freehand line." With these contrast the criticisms offered by the other group. "That

¹ Many of our older readers, especially those who had been influenced by the teaching of Morris and his followers, were inclined to protest against what they supposed to be 'the gross deterioration in printing produced by the application of mechanical methods'. But the printing press is itself essentially a machine; and such protests are five centuries too late. Shaw's secretary relates an instructive story. "G. B. S. wanted the type (for his collected edition) to be set up by hand: in the Morris tradition, he scorned machinery and the usurping monotype." The managing director of R. & R. Clark arrived with two specimen pages, and invited him to pick that which he thought the best. Shaw unhesitatingly chose the page which (as it turned out) had been set by monotype! So far from debasing the quality of book production, the introduction of mechanical type-setting has greatly enhanced it: and there can be little doubt that what has been called 'the revival of printing' and the present prestige of British typography have been largely a product of the courageous policy of the Monotype Corporation, who, 50 years ago, embarked on a progressive recutting of classical type-faces, supplemented by new designs by artists like Bruce Rogers and Eric Gill [23].

² During the revival of learning initiated by Charlemagne after the dark ages (c. 790), Alcuin of York was invited to the Abbey of St. Martin at Tours to superintend the copying of Church books. The story goes that Charlemagne, who himself desired to write, declared that "a hand accustomed to the sword could form only the simplest shapes"; hence the substitution of the plain half-uncial forms for the confused and multifarious Merovingian hands. Being without ligatures, this simplified style lent itself admirably to the requirements of movable types when the time arrived.

³ Those readers who wish to examine further the typography of the printers named in the following paragraphs will find original specimens of the work in the cases in the King's Library of the British Museum which illustrate the History of Printing.

⁴ Some 'old faces' are now supplied with an alternative set of figures ranging on the line.

sort of type (Garamond and Fournier) may have been quite all right when people wore picturesque clothes and lived in Renaissance palaces: in a technological age you want a plain technological type." "This kind of lettering (Baskerville) sets me wondering who drew those pretty curves, when I ought to be thinking who wrote this passage and what did he mean." "Modern printing should be like modern building, purely mechanical and functional, not a phoney revival like late Victorian Gothic or pseudo-Tudor house-fronts."

It will be remembered that the factorial analysis of the specimens in our series subdivided the Old Faces into two main sub-groups, called for purposes of reference 'Continental' and 'British'; and the former in turn was re-divided into what we shall call 'Italian' and 'French' respectively.

1. *Continental*. The most distinctive features of the 'Continental' subgroup are the crossed W and the splayed M. Both these features were criticized by teachers and others who thought them "too eccentric" for children's books or "too archaic" for scientific books. "The legs of the M seem to be slipping apart", says one. "Nowadays", says another, "double-U is no longer a double letter, and V no longer stands for U." Others, however, thought these minor variations "add life and interest to the printing".

(a) *Italian*.¹ There is no single criterion distinguishing all the specimens in this subdivision from the next. To judge by the comments of our readers, the common characteristic is largely negative, namely, a freedom from the decorative tendencies that are so marked in the other type-faces in our continental series, particularly the French. The nearest approach to a positive diagnostic clue is the curve of the *v* and *w* in the italic founts—neither angular nor rounded, but (to quote one reader) "a bit *nouvel art*". However, so far as it can be defined, what seems to have led most of our readers to rank all three specimens together at much the same level, either high or low according to their taste, is an impressionistic quality difficult to describe, but summed up by one of them (a little sarcastically) as "a chaste art-and-craft appearance".

Bembo (270).² This type, a comparatively recent revival, is perhaps the best representative of the early classical design from which all our later roman types are descended. It won high praise from both our 'literary' and our 'scientific' groups. A tiny point which raised it (with Plantin) above all the other 'Franco-Italian' types was the lower case *j*, with its generous curve and bulb, which prevents any confusion with *i*. The *x*-height is small, to leave room for the long ascenders and descenders; indeed, the ascenders are taller than the capitals—a feature occasionally criticized: (as one reader remarked, "the uneven heights of the first two letters in 'The' or 'When' suggest that the printer had unintentionally picked them from different founts"). As to the italic (which comes from a different source, see p. 54) opinions were divided. Teachers who were members or admirers of the 'Society for Italic Handwriting' praised the oblique serifs and the sharply curved terminals in the lower case, and thought the use of this type face in reading books might be associated with a revival of the so-called Italic style for children's script. On the other hand, non-academic readers often considered these features "rather mannered". The italic *y* ("more like a Greek gamma with a serif to its tail") was almost universally condemned.

Veronese (59). This was one of the earliest of the artistic designs cut by the Monotype Corporation, and was brought to them in 1911 by J. M. Dent (publisher of the 'Temple Classics' and 'Everyman's

¹ The letters in the earliest printed documents (emanating from Gutenberg's firm, c. 1454) were based on a degenerate vernacular ('Burgundian Bastardas'—full of sharp points like Gothic architecture) which had become current North of the Alps and was derisively dubbed 'Gothic' by Vasari. As 'Schwabacher' and later 'Fraktur' it was proudly preserved throughout the centuries as the German national style. Elsewhere the change to so-called roman letters was due to certain historical accidents.

After driving out the English, Charles VII (the king crowned at Rheims during the days of Joan of Arc) sent Nicholas Jenson to Mainz to study the new invention. When Gutenberg's foundry was burnt in the sack of Mainz, two of his assistants fled to Subiaco near Rome, and there installed a printing press, the first to be set up in Italy, at the Monastery of Saint Scholastica, later transporting it to the Palazzo Massimi in Rome. Jenson apparently went with them; but he eventually moved on to Venice (1470). Since the books were intended for Italian scholars, it was natural to adopt the old *littera antiqua* or *humanistica* then in favour with the leading humanists. Jenson's designs were based on the best manuscripts, and are the most highly praised of all classical faces: (for reproductions see [5] and [25]). On his death his material passed to the father-in-law of Aldus Manutius. The name 'roman' apparently originated in France, and was used to distinguish the Italian type-faces both from the 'gothic' or black letter and from Aldine 'italic': it seems to refer, not to Jenson's adoption of monumental Roman capitals for his majuscules, but to the style adopted by the printers at Rome.

² In 1495, soon after setting up his press at Venice with material from Jenson, Aldus Manutius printed a small tract, *De Aetna*, written by the 25-year-old Venetian poet Pietro Bembo, one of the leading humanists, famous for his revival of Ciceronian Latin, and later Cardinal and Secretary to Leo X. The type, cut by Griffo of Bologna, differed somewhat from the designs of Jenson: the *e*'s and *h*'s have their more familiar shape; the capitals are narrower, and their slab serifs abolished. Aldus himself seems to have discarded this type almost at once in favour of yet another version, cut for his still more celebrated *Hypnerotomachia Poliphili*: it was this that apparently furnished the basis for Garamond's French types, and so ultimately for Caslon and his successors.

Those who wish to judge the suitability of Bembo for psychological work will find good instances of it in Ryle's *Concept of Mind* (Hutchinson, 1949) and Valentine's *Parents and Children* (Methuen, 1953).

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Library"). It was modelled, partly no doubt as a result of William Morris's influence, on a rather heavy Venetian 15th century original.¹ As several of our readers observed, it is suited only to a restricted range of publications. Many teachers, particularly headmistresses, thought it excellent "for children's poetry books" or "for Shakespeare". The points that most frequently aroused comment were the slab serifs of the M and N, the sloping stroke of the e (both reversions to Jenson's design), and the thickening of the horizontal strokes in the z. The italic is a modified version of that associated with the Italian and French type-faces, rounded, expanded, and slightly thickened to secure greater legibility.

Centaur (252). This type-face was originally designed by the American typographer, Bruce Rogers, for Houghton Mifflin.² The roman fount is modelled on Jenson's roman, with triangular serifs for the lower case, but without Jenson's slab serifs for the capitals. The most distinctive features are the sloping cross-stroke for the lower case e, the incurved shank of the italic *h* (both a reversion to Jenson's designs), the absence of thickening in the tail of the *j*, and the straight thin stroke of the *y*, thickened at the lower end. In the re-drawing, the type seems to have lost much of the robustness of Jenson; and was even criticized by some of our readers as "self-conscious" and "art-y".³ The italic, designed by Frederick Warde, is modelled on that of Arrighi (see p. 54).

(b) *French*.⁴ The two peculiarities most frequently criticized in this group were the pointed bases of italic *v* and *w* and the swash descending tails of the italic *z*: most of our readers thought such letters highly unsuitable for algebraic symbols, and many disliked them even for general use.

Garamond (156). The roman resembles the Venetian characters of Aldo, but the *j* preserves the old form, that of an elongated terminal *i*: the similarity caused a good deal of unfavourable comment. But the chief target for criticism was the italic—"sometimes too narrow, sometimes too wide, and the capitals sloping at inconsistent angles", reflecting "an unskilled stage in the development of type-design". (Compare the slanting *Q* and *S* with the nearly upright *R*, the splayed *A*, *V*, and *x* with the narrow *S*, *B*, and *y*.) The *Q*, "shaped like a written 2", the curly *k*, the long-tailed *z*, the sharp-based *v* and *w*, the *g* with its wide lower bowl, the *y* with its back-swept tail, and the primitive hooped *h*, "almost like a *b*", were disliked by many. A few warmly praised these peculiarities, as "giving the type a marked character of its own".⁵

Granjon (Linotype).⁶ We included this because we were told that it was one of the most popular linotype faces. The design has many similarities with the preceding: e.g., the *j* tapering to a point. It differs chiefly in using the same form for the capital *J* (almost a straight line), avoiding the crossed *W*, and reverting for the italic *v* and *w* to the form used in Bembo (the last two features probably account for its being ranked above Garamond). Its most distinctive peculiarity is the long downward tail to the italic *k*—criticized by all who disliked any tendency to flourish.

¹ A similar type, based mainly on Jenson's roman, had been designed by Emery Walker for the short-lived but celebrated Doves Press (1901) at Hammersmith. It should be noted that much of William Morris's typographical work was due to the skill and learning of Emery Walker. Morris (according to his daughter) after hearing a lantern lecture by Walker on ancient type-faces, suggested that they should join in founding the Kelmscott Press (1890). Emery Walker later became Chairman of the Consultative Committee on Printing Schools under the L.C.C. (1920).

² Bruce Rogers joined Emery Walker for a while at Hammersmith and later served for a time as adviser to the Cambridge Press.

³ The psychologist will find an interesting example of this type—italic as well as roman—in Sherrington's *Man on his Nature* (Cambridge University Press, 1940).

⁴ The essential characteristics of what are now called 'old faces' became fairly well fixed during the later years of François I—the golden age of French typography—largely as a result of his passion for Italian art and culture. Claude Garamond (c. 1535), the most successful of the French type-cutters of the period, produced what eventually became the standard European type outside Germany. It seems certain that copies of Aldus's work reached Garamond in Paris; and, as we have seen, it was on these that Garamond's designs were based.

In the 17th century, after a temporary decline, French printing, like French scholarship, revived under Richelieu; and the Imprimerie Royale, established by him in 1640, started with what were taken to be Garamond types. Thus, the style that had been introduced a century earlier continued to dominate French printing, with minor variations, until it was superseded by a 'modern face' at the end of the 18th century. A 'Garamond' type was recut in France in 1898, and it was one of the first of the classical faces to be cut by Monotype. Mrs. Beatrice Warde ('Paul Beaujon'), however, has shown that the punches acquired by the Imprimerie Royale in the 17th century were not, as they supposed, those cut by Garamond, but were in fact designed, nearly a hundred years later, by Jean Jannon of Sedan in 1621 [8].

⁵ Professor Saw's *Leibniz* (Penguin series, 1954) is set in Garamond. It was, we think, an unfortunate type to choose for Kenyon's *The Bible and Archaeology*, where the juxtaposition of the italic *g* and *y* (as in *Egypt and archaeology*) requires a very ugly logotype.

⁶ Granjon was printer to Henri II (c. 1557) and afterwards to Pope Gregory XIII. The type, produced by G. W. Jones for Linotype, was based on 16th century French type faces. Mention should perhaps be made of another fount recently cut by the same designer, and called Estienne (after a celebrated 'Royal Printer' of the same period). It has the old-fashioned italic seen in Garamond, but it is chiefly noticeable for its long ascenders and descenders—a feature revived by Eric Gill in his 'Perpetua'. Estienne and several other faces we were forced eventually to exclude for fear of overloading our tests.

Fournier (185).¹ Several readers were puzzled by the serif to the foot of the roman b (seen also in Bodoni); and the lower case j (with no blob) was again the subject of criticism. Many also thought the roman fount too condensed, especially the M and Z: (the 12-point lower case alphabet has a length of only 130 points, i.e. 1·8 in., as compared with Garamond which has 144 points, i.e. 2 in.). The italic evoked the most opposite views. Unlike the preceding founts, instead of providing a new set of designs, it is to a large extent merely a sloping version of the roman: thus the *m* and *n* have sharply sloping serifs instead of curved initial hooks, and the upper right arm of the *k* has no loop. Several considered the inclination excessive (19° instead of the Garamond 12°); and the oblique bowl of the *g* and long downward tail of the *z* were frequently condemned as "irritating" or "trying too obviously to be quaint".

Plantin (110).² This type face, designed in 1913 by the Monotype Corporation, was the first produced for use on coated paper.³ Its blackness on uncoated paper has made it popular for children's books. The italic, with the well rounded base to *v* and *w*, departs widely from the French designs, and was thought to be well adapted for mathematical use. Nevertheless, rather to our surprise, it was far from popular with our scientific readers—chiefly because of the roman j ("too like i"), the crossed W's, and the italic *J* and *Q*. One or two noted the gap in the P between the upright and the end of the curve, and asked if it was deliberate or accidental; and several disliked the flat top to the capital A.

Ehrhardt.⁴ The roman j tapers to a point; both arms of the C have serifs; the M is splayed; the italic *J* has an unpleasantly low bar; and in both founts the Q has an elongated tail—features often prompting unfavourable comment. Several also disliked the somewhat irregular bowls of the roman and italic g's. The characteristics most frequently condemned, however, were the peculiar italic *w* (joined head-strokes, pointed bases, while that of the *v* is round) and the even line of the zero—"more like a circle than a numeral". This was the least popular of the old faces.

2. *British*. England, unlike Germany and Italy, had no national pride in printing, and readily borrowed from the other side of the Channel. Caxton's first book (*The Game and Playe of Chess*, 1475) was printed at Bruges in an unattractive Gothic style; and one of his later types (based on the formal liturgical hands—*textura*⁵) became the basis of the so-called 'English black letter'. Shortly after the establishment of the Royal Society, Dr. Fell,⁶ Bishop of Oxford, imported punches from Holland, which then had almost a monopoly of type-founding, and with these (which still exist) set up the Oxford Foundry. The first competent engraver of types in England was William Caslon, whose foundry has survived to the present day.

The type-faces classed together in the 'British' group by our factorial results are distinguished by several obvious points from the French and Italian. The roman letters, particularly the capitals, have a wide set. The W's are uncrossed, and the M's unsplayed; the roman Q (except in recent forms) has a swirled tail. The j has a well rounded terminal ending in a bulb. The italic comes closer to the English running hand, and is somewhat condensed. The Dutch origin is traceable in the high bar and swirled head to the italic *J*, and in the curved serifs of the rounded italic *v* and *w*.

Caslon. Caslon started a new foundry in 1720, modelling his letters on those of van Dijk, but greatly improving their delicacy. The result was a distinctly English face, which (except for a

¹ The Fourniers managed the Le Bé factory in the 18th century. P. S. Fournier ('le jeune') proposed the 'point' system in his *Manuel* (1764), and started modifying the old French designs in the direction of the *gout hollandais*.

Bertrand Russell's *Inquiry into Meaning and Truth* (Allen and Unwin, 1940) and Murdo Mackenzie's *Contrast Psychology* (Allen and Unwin, 1952) are set up in 12-point Fournier type.

² Towards the close of the 16th century, superiority in printing, as in other forms of scholarship, passed for a time from Roman Catholic France to Protestant Holland. Christopher Plantin (1514-89), born near Tours, established his press at Antwerp, and shares with Christoffel van Dijck (type-cutter for the Elzevirs) the credit of producing some of the finest Dutch work. Their designs were sturdier versions of those produced by Garamond and Granjon. There is an Intertype Plantin with more irregular italic. Neither version is by any means an exact reproduction of the original.

³ It stands up well to the demands of high speed rotary printing. The most familiar instance of its use is *The Listener*. For the psychologist an instructive example is the new edition of Trotter's *Instincts of the Herd* (Oxford University Press, 1953), which shows the blackness of the type on uncoated paper.

⁴ The type appears to have been suggested by that used by Ehrhardt of Leipzig (c. 1720) and derived by him from the Dutch foundry of Anton Janson.

⁵ The so-called *lettre de forme*, a large upright hand, with sharp angles and no curves, having a woven 'texture': (Cf. 'Fair as a text B in a copy book,' *Love's Labour's Lost*, v, ii, 42). By the 15th century it had superseded the fine hand of the Winchester School (11-12th century, a blend of Anglo-Irish with Carolingian). The Authorized Version (1611) was printed in *textura*. Caxton himself explained that his books were "not for a rude vplondyssh man to rede, but onely for a clerke and gentylman", and he therefore aimed at "a meane bytwene the playn and curyous" (Prologue to *Eneydos*).

⁶ His name survives in popular memory from the doggerel parody of Martial's 33rd Epigram, written by Tom Brown as an undergraduate, after Fell (then Dean of Christ Church) had expelled him. Besides Caxton's press in the precincts of Westminster Abbey, presses had existed at Oxford and St. Alban's from the 15th century. Of the several early foreign printers who set up presses in London, Richard Pynson, afterwards printer to Henry VIII, used a 'white letter' to print an *Oratio* for the papal nuncio (1509).

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spell of neglect in the 19th century) has remained in continuous use for over 200 years.¹ Perhaps because the Declaration of Independence was printed in Caslon, it has been still more popular in the U.S.A. The minor irregularities of shape and weight give it, as our readers put it, a "homely, unassuming, old world look"; and led others to condemn it as "unskilled" or "primitive".

In the roman the distinctive features are the wide H, M and U—the H indeed being frequently criticized as "disproportionately broad". Several disliked the obliquely flattened top to the A, and asked if the type was not slightly battered. The irregularities are most marked in the italic. In both Caslon and Baskerville the italic Y resembles a Greek upsilon (a shape which excited repeated criticism); the lower case w has an open loop; and the C in both roman and italic has a well marked serif to the lower arm (sometimes omitted in smaller sizes of Caslon roman). With the Caslon italic the downstrokes to the angular letters, A, V, and W are parallel to those of the square letters, H, M, I, K, etc., so that the former seem to be toppling forward. As a result, the gap between the capital initial and the rest of the letters sometimes breaks the word in two—a point seized on by most of the teachers.²

*Baskerville.*³ The most conspicuous peculiarity of Baskerville is the pointed unserifed junction of the two inner strokes of the large and small W—a feature commended by many of our readers, who argued that "in English W is a single sound, not two consonantal V's". In the g the lower bowl is not completely closed. And practically all the letters display an increased contrast between the thin lines and the thick.

Owing to a free use of kerned letters the italic has an individuality of its own. The terminals are rounded, and the thickening has shifted from the bases to the down strokes—characteristics suggestive of elegant penwork. Compared with the roman, the italic shows even greater condensation than Garamond, and was consequently criticized as "crowded". Considering the popularity of this type with many publishers, the criticisms we received were unexpectedly frequent. Some thought the general effect "a little too genteel". The decorative tendencies of the italic excited both praise and blame. The "pothooks and hangers" of the italic *m* and *n* and the upstroke to the italic *p* were said to be "suggestive of copperplate engraving"; the curves of the *k* (as in Fournier devoid of a loop) and of the *z* were often considered "fanciful", and the swash italic *K*, *N*, *T*, and *Z*, and the generous tail of the *Q*'s (roman as well as italic) "much too distracting".⁴ On the other hand, several readers placed this type at the top of their list; and many picked out the very characteristics that others so strongly criticized as "making the type far more interesting than ordinary humdrum print".⁵

Old Style. The design that originally bore this name (cut in 1860 by Phemester for a well known Victorian firm, Miller and Richard) sought "to supply a type with old face qualities without the archaic features of Caslon".⁶ It was so successful that it was quickly copied by most other founders in this country and by printers in Germany, Scandinavia, and the U.S.A. Thus, by the beginning of the twentieth century the majority of books were printed either in a variant of Old Style or in one of the 'Moderns': and probably these publications moulded the notions of our older readers as to what the proper shapes for English letters should be. There are numerous minor variations of the 'Old Style' face: e.g., Monotype and Intertype have an A with a pointed apex, while Linotype, like the earlier founts for handsetting, usually has a flat top. We used the Monotype version (Series 2)—one of their "early bread and butter founts" (as they call them) cut in 1901. The serif on the upper limb of C and G has a well marked slope, and the G and b have spurs. The absence of hairlines and the even colour were praised by most of our readers. Comparatively few *specific* points were criticized; but a number of our younger literary readers thought the general appearance "rather insipid", or "harmless but lifeless".

¹ Its renewed popularity at the beginning of the present century was due partly to Bernard Shaw. Shaw supervised all his printing: (cf. his paper 'On Modern Composition', *Caxton Mag.*, 1902). The plays had to be set in Caslon long primer unleaded—"no rules, no flowers, no headings, side or cross". But how many have been repelled by the solid grey oblong pages of his prefaces, often without a single indentation!

² For an example of Caslon see G. F. Stout, *God and Nature* (Cambridge University Press, 1952).

³ John Baskerville (b. 1706) was a writing-master at Birmingham. After seven or eight years spent on designing a type suitable for "books of consequence", he became printer to the University of Cambridge. His smooth wove paper and novel printing techniques made it possible to produce a far clearer and more delicate impression; and, as Macaulay puts it, his *Virgil* "went forth to astonish all the librarians of Europe".

⁴ Monotype provide their Caslon fount with alternative italics possessing similar flourishes, though (except for titling) they are rarely used.

⁵ For examples of Baskerville, see Ayer's *Language, Truth and Logic* (Gollancz, 1946) and Ferguson's *Young Delinquent in his Social Setting* (Oxford University Press, 1952), where the non-ranging numerals and the swash italic capitals in the tables seem open to criticism. Baskerville has of late been an exceedingly popular type for ordinary novels.

⁶ Caslon was revived in 1844 by the Chiswick Press for a fictitious 17th century *Diary*. The old Fell types were resurrected in the following year, and used to print Tupper's *Proverbial Philosophy* and the *Oxford Book of English Verse*. In the last quarter of the century Ruskin, Emery Walker, William Morris, and Charles Ricketts initiated "an aesthetic typographical renaissance" that eventually made "modern English printing the soundest in the world" [5]. See above, p. 48, footnote 1.

Imprint. This was "an all purpose design" cut by the Monotype Corporation in 1912 to the specification of G. T. Meynell and J. H. Masson for a new monthly review called *The Imprint*. It proved to be one of the most popular faces in our series. The general style is that of Caslon; but the type is larger on its body, and gets rid of the peculiarities that strike the modern eye as primitive—e.g., the marked and irregular slope of Caslon italic, the serif to the lower arm of C, and the curved italic Y. The roundness of the lower case italic resembles that of Baskerville, but the central loop to the italic w is not visibly open. The one feature most frequently criticized was the tiny tail to the roman Q.¹

Times New Roman. The *Times* newspaper, originally set in a rather crude old face, changed early to modern (1799), and kept it for over a century. On October 3, 1932, the paper arrived at the breakfast table in an entirely new type, specially designed by Mr. Stanley Morison (Reader in Bibliography in the University of Cambridge and Typographical Adviser to the Cambridge University Press and the Monotype Corporation). A year later the design was released for general use. At the present day it is probably more widely used than any other face. For its original purpose, to combine legibility with economy of space, it is admirably adapted—large on its body, compressed in spite of its x-height, yet with well open counters, and furnished in its original form with short space-saving ascenders and descenders. We found it amazingly legible in the smaller sizes.

Its more obvious characteristics classify it with the 'old' faces. The serifs to the capitals are bracketed; while those of the lower case are wedge-shaped; the shading of the lower case roman is strongly biased (indeed, the tops of the curves in b and p and the bottoms in c, e and q were sometimes criticized as "disproportionately thick"). C and G are clearly distinguished; the J is non-descending; the Q has a small central claw tail (perhaps leaving the letter "too much like an O"). The italic is only slightly sloped (16°), and tends to repeat the design of the roman: e.g., the *i, j, m, n*, and *p* commence with straight serifs, and the *v* and *w* have angular bases. Mathematical readers objected that some of the italic was unsuitable for algebraic equations, in particular the *v*, which is indistinguishable from a Greek *nu*. On the whole, however, this face was one of the very few that were popular with both the literary and the scientific groups.²

Perpetua (239).³ Because of its exceptional interest, we included this type face in our first and larger series; but, since it has rarely been used as a book face,⁴ we dropped it in our final experiments. The roman *looks* an extremely legible face; but many readers found that after a while it proved rather tiring. The italic aroused the most conflicting judgments, even among our literary group. There was, however, a general agreement that, for text matter as distinct from a title page,⁵ its peculiarities tend to thrust themselves between the author and the reader. Accordingly, in view of its rather distracting quality and the unusual form of the numerals, we had little hesitation in deciding that it was quite unsuitable for mathematical publications.

B. *Modern Faces.*⁶ The distinctive characteristics of the so-called modern faces are (i) the vertical instead of biased shading, (ii) the marked contrast between the thickness of the 'down strokes'

¹ For examples of Imprint the reader may take McDougall's *Psychology* (Oxford University Press, 1952, originally set in Scotch Roman, 1912) or Burt's *Subnormal Mind* (Oxford University Press, 1935).

² This Journal and the *Brit. J. Med. Psychol.* are set in Times New Roman.

³ Perpetua (called after an African martyr) first appeared in an exhibition of types arranged at the St. Bride Institute in 1930; but it seems to have attracted little interest from the printing trade until after the war. It was based on drawings made by Eric Gill, *not* (so he says) with special reference to typography. The roman follows the style of the best chiselled inscriptions of the Roman era, with Gill's own stone-carving as an intermediary stage. The narrow E and S, the slightly splayed M, the generous tail of the Q's, the thrust-out leg of the R's, and indeed the proportions generally, seem manifestly copied from the celebrated panel on Trajan's Column. The U, a letter which does not exist in Latin, is uncial. Elsewhere Gill declares that the designs preserve "that commonplaceness and normality which is essential to a good book type". But much of the italic is neither commonplace nor normal. With both faults the idiosyncrasies are best seen in the larger sizes. The stress is usually vertical; the serifs are hairline but bracketed, horizontal in the roman, oblique in the italic; the O is circular; the E equal-armed; the bottom of the d and the top of the q are flat; the ear of the g is horizontal; the upper stroke of the 5 unusually long. The italic is a slanting roman. The *B, D, R*, and *P* have flourished headstrokes, and the *U* has both its verticals thickened. But the most striking peculiarity is the loop of the *g*, which turns up and joins the bowl, so that the letter resembles an inverted *B*.

⁴ It has recently been used for the text of several Penguins (e.g. *Selected Poems*, by T. S. Eliot, 1952); and the more recent linotype version, called Pilgrim, has been adopted for the current issue of *The Yearbook of Education* (Evans, 1955). To the ordinary reader the style will probably be most familiar from its use for headlines in newspapers and advertisements catering for educated or sophisticated readers (e.g. those of the Arts Council, H.M. Stationery Office, and even the wrappings of household commodities intended for the 'more refined classes').

⁵ For titling and display there was a general agreement among our testees that Perpetua was "the most delightful of any style of type". Of the type-faces suggested for the cover of this *Journal* it received by far the largest number of votes.

⁶ The so called 'modern' faces became popular in France at the close of the 18th century when 'classical' (i.e., Roman) art became fashionable at Paris. The alleged model was the rigid sculptured lettering—the *capitalis quadrata*—of the ancient inscriptions, many of them newly discovered, which were deemed aesthetically superior to the freer and more flowing characters traced by the monastic quill. The

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(i.e., those that are vertical or run down from left to right) and the thinness of the curved strokes and the 'upstrokes' (i.e., those that run up from left to right), (iii) the fine horizontal unbracketed serifs (iv) the figures ranging on the line, and (v) generally, the geometrical and rigidly mechanical structure of the design.

As we have noted in our studies of other forms of art, there seems to be a kind of 'temperament' (if we may use such a word to designate what is quite as much a cultural, epochal, and often national attitude as an effect of innate constitution) which tends to admire geometrical, symmetrical, and perpendicular qualities in human art and to favour a scientific or technological design as contrasted with what is imaginative or emotional or gives free rein to fancy—in short, a classical taste rather than a romantic. During periods in which one or other of these tendencies becomes dominant in sculpture, architecture and literature, it generally appears, after a little delay, in commercial and domestic art, and ultimately in typography. The correlation between the various manifestations was obvious not only in the results of our tests, but also in the introspections. People who showed the preferences of the 'stable introvert' in other forms of aesthetic appreciation (cf. 18, p. 297) seemed also to reveal them in their preferences for type faces; and frequently they used the same arguments to justify both forms.

Here, as before, the factorial results subdivided the various type faces belonging to this broad class into two subgroups, the Continental and the British.

1. *Continental.* In the 'Continental' subgroup the characteristics distinctive of the 'modern' face appear most clearly. The 'British' as usual show an inclination to compromise.

Bodoni (135).¹ Morris vehemently objected to "the sweltering hideousness of the Bodoni letter, the most illegible ever cut, with its preposterous thicks and thins". Our readers generally ranked it last of all. Numerous incongruities were noted. Since the alphabet includes letters, like V, W, X, and Y, which are composed solely or mainly of symmetrically arranged oblique strokes, it is impossible to apply the principle of vertical thickening with complete consistency. Moreover, in the upper case the inner limbs of the W cross, in the lower they meet in a point, as in Baskerville. The C has a serif to the lower limb, like Baskerville; the b a foot serif, like Fournier. The top of the t is cut off flat. The italic is only slightly sloped (10°): some letters begin with a horizontal serif like printed roman; the v and w (but not the u) with a rounded curve like a running script. The right hand upper limb of the italic y is curved outwards; and in both roman and italic the capital J falls only a little below the line—"as though the printer could not make up his mind". The squareness of certain letters, the correct symmetry of others, the parallelism and rigidity of the lines, led many readers to complain of the 'geometrical' design: "it might almost have been drawn on squared paper with a ruler and compasses, and then carefully shaded in." On the other hand, several of our subjects observed that, owing to its emphatic character, it seemed highly suited (in the larger sizes) for commercial advertising or headlines in newspapers.

result was a somewhat stiff and pompous style, like that of academic painting and sculpture during the years when Louis David was director of arts. It should be noted that an upright style of writing existed long ago in this country (e.g., that used for the Lindisfarne Gospels, an insular adaptation of the half uncial hand). The alphabet then in vogue contained no v, w, or y: with these letters, in order to avoid making *both* downstrokes thick, the method of writing has to be changed; and so an obvious incongruity arises.

Many teachers who favour an upright style of writing require their pupils to hold the pen at right-angles to the ruled or imaginary base line on which they write. The upright characters of the early manuscripts, however, were obtained, not by changing the position of the hand, but by cutting the nib obliquely.

The common notion that the 'modern' style was first introduced by Bodoni and then taken up by the Didots is quite mistaken. Similar characteristics are traceable in several Italian manuscripts of the late renaissance. Italian architects and painters, and later the French savants of the Académie des Sciences under Louis XIV, had constantly interested themselves in inscribing letters in squares, triangles, and circles according to definite proportions, and in attempting to formulate artistic taste in terms of mathematical principles. As we ourselves discovered, it was a popular hobby with several male teachers and craftsmen who took our tests: see, for example, the 'general remark' made by one of our readers, and quoted above under 'rationalizations' (p. 40).

¹ Giambattista Bodoni (b. Piedmont, 1740) was head of the *Stampa Reale* at Parma. The rather dazzling brilliance of the contrast between the heavy main strokes and the finer hair strokes, and possibly the fact that such type required good paper and was itself a sign of an amazing technical precision, rendered the new style popular for all serious work. Bodoni printed editions for Gray and Horace Walpole, who warmly applauded the 'new continental workmanship'. He started with French models. Indeed, the thin horizontal unbracketed serifs that are so characteristic of the 'modern face', as well as the narrowing of the letters, are already discernible in type cut by Grandjean (1745), who had been ordered by Louis XIV to produce a new design that should be the monopoly of the Louvre—the *Romain du Roi*. But it seems to have been the new delicacy and emphasis introduced by Baskerville which Bodoni and the Didots chiefly admired and endeavoured to magnify. The new Bodoni Press in Italy has recently produced remarkable examples of the typographer's skill. In this country, however, it has become confined to titling, advertisement, and letter press accompanying art books on ultra smooth paper.

The versions of 'Bodoni' cut by British and American foundries are more open than the original, and the heart shaped italic v designed by Bodoni has been discarded (except by German printers) for a shape conforming with the w.

Didot (520).¹ This type face is intermediate between the older French faces and Bodoni. The italic is almost identical in form with the roman, and its inclination is slight. The wide *H* and *U* and the pointed *j* were freely criticized.

Walbaum (374). This is a German 'modern' type (1810), revived by the Curwen Press and later by Monotype. The design is based on Didot; and both roman and italic are wide and therefore readily legible. The roman, with its non-descending *J*, spurred *b*, *e* with a large counter, and square-topped *t*, suggests a lighter version of Scotch Roman, though the pointed *j* indicates its French origin; the italic *v* and *w*, though wider, are reminiscent of Bembo and the double curved *y* of Bodoni. The descenders of the *p* and *q* have no serifs. Walbaum and Didot were among the least popular faces.²

2. *British*. English printing has always been characteristically light. Hence in Britain, even modern book faces have tended to avoid the excessive thickening of their continental prototypes, though in the 19th century Thorne and his imitators set a fashion for 'fattened' styles that have remained popular with commercial firms. For the most part anything glaringly foreign was discarded, and several distinctively English features due to Caslon and Baskerville were preserved. At the same time the British versions introduce one or two points that are wholly new.

Bell. What is sometimes called the earliest English modern face was cut in 1788 by Austin for the London bookseller and publisher, John Bell, who was the first to discard the long-tailed *s*. In contrast to the condensed modern faces of Continental printers, its well-rounded letters give it a distinctly British look. It was recut by Monotype from the original punches found by Mr. Stanley Morison in a lumber-room of Stephenson Blake (the Caslon Letter Foundry). Like other modern faces, it has horizontal serifs, perpendicular shading, and a large counter to the roman *e*. It has a straight serif to the italic *j*, and a plain italic *J* standing on the line (though the roman drops below). On the other hand, it retains the peculiar italic *Y*, with the curved upper arms adopted by Caslon and Baskerville, and reverts to the excessively sloped *V* and *W* of Caslon. The lower limb of the italic *k*, *K* and *R* are curved, like those of Baskerville; and similar curves now appear in the roman *k*, *K*, and *R*. The italic *x* is also curved—formed by two *c*'s placed back to back. These curvilinear innovations were widely criticized by our readers; but with the scientific group it was one of the most popular of the older founts.³

Scotch Roman (46). In matters of literature and the arts Scotland has always kept in close contact with France; and there has been, and still is, some degree of trade rivalry between the printers of Edinburgh and Glasgow and the presses of Oxford, Cambridge, and London. It is not surprising, therefore, to find that the changes distinctive of the new French printing at the close of the 18th century were quickly reflected in Scottish publications. In 1815, Alexander Wilson, a Glasgow printer, introduced what he called 'Scotch modern face'—a sturdier version of Didot's types. The ascenders and descenders are shorter, and the serifs have slight brackets. The most distinctive features are the non-descending *J*, the *Q* with the tail beginning with a little circle inside the counter, and the curly lower limb to the *R* ending with an upward turn like an italic *m* or *n*. As in Bodoni the top of the lower case *t* is square. The italic is not unlike that of Baskerville, but less condensed and more emphatically shaded. The *p*, however, begins with a hook like *i*, *j*, *m* and *n*; and the *x* resembles that of Bell. The *y* is new, with a round bowl like that of the ordinary running hand. Indeed, many of our readers complained that the italic resembled the pseudo-copperplate writing of the cheap printed visiting card, "with 'thin upstrokes and thick downstrokes', as the old fashioned schoolmaster used to say". This became one of the most popular founts of the 19th century.

Modern Series 7. A 'modern' type face (Series 1) was cut by Monotype as early as 1900. Series 7 (an 'extended' version) includes over 600 'mathematical sorts,' and is the fount adopted by the authors of *The Printing of Mathematics* (Oxford University Press, 1954). It is thus a specially important type face for our purpose. In its most obvious characteristics it resembles Scotch Roman. Most of the serifs, however, are unbracketed; but the thin verticals have brackets: thus *U* has a hair-line at the top of the left hand upright and a triangular serif at the top of the right hand—an inconsistency which several readers noted. Unlike Scotch Roman the roman *t* has a pointed top as in most other type faces. In the italic, *g* has a plain oval bowl, like a written *g*, and a tail like the *y*; the *w* has a plain central downstroke instead of a loop; the *v* and *w* start with a simple hook (like *m*, *n*, and *u*), not with the circumflex curve of older British founts.

Among our scientific readers Modern 7 appeared the most popular of all. The non-scientific criticized it sometimes on patriotic grounds, sometimes on aesthetic: many objected that it had "an un-English" or a "French" look; others thought it "too rigid and mechanical"; several

¹ In France the *gout nouveau* was developed by the Didot family at the very beginning of the 19th century: the most celebrated were printers to Monsieur (afterwards Louis XVIII) and the Comte d'Artois (afterwards Charles VIII). The elder, F. A. Didot, himself a noted classical scholar, reformed the point system, making the unit equal to $\frac{1}{16}$ of the pre-metric inch. Their design, still more condensed, has remained the standard style for French printing, where, during the last 150 years, typography has changed far less than in this country.

² Walbaum is used for Grey Walter's *The Living Brain* (Duckworth, 1953).

³ *English Social Differences*, by Professor Pear (Allen and Unwin, 1955) is printed in 11 point Bell.

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who laid claim to typographical taste believed "it was time that scientific publications attempted a style of printing less crude" (or "less inartistic" or "less old fashioned", i.e., 19th century).¹

Italic. In general italic type differs so widely from roman that we considered it essential to obtain preferential orders for the two founts separately.

What we now call italic was first introduced by the Venetian printer Aldus Manutius in 1501 for his pocket editions of the classics. For a more popular kind of reader it was natural to turn to a more popular kind of letter—the everyday cursive which had grown up side by side with the formal. Moreover, a running hand tends inevitably to slope; and the slope allows greater condensation and so economizes space: (with Baskerville the italic takes only 87 per cent. of the space required by the roman). Griffo, who cut the type, is said to have taken Petrarch's writing for his model.² These early attempts were somewhat crude and found few imitators: in particular much difficulty was experienced in sloping the roman capitals so as to give them the appropriate inclination. The standard italic is derived not from Aldo but from Vicentino (Ludovico degli Arrighi of Vicenza), a writing master in the Vatican Chancery, who (like Baskerville later on) turned printer and published (1522) a copybook claiming to teach *littera cursiva o cancellerescha*: this was a neo-Carolingian minuscule, used for papal 'briefs' (i.e., short notes and informal correspondence); and nearly all the 'swash' capitals that appear in later faces are to be found among Arrighi's decorative majuscules. Robert Estienne,⁴ one of the most celebrated scholars and printers in the reign of Henri II, adopted Arrighi's letters as his model; and most later italic founts are descended from that. 'Italic' remained for long an independent rival to the 'roman' letter. Being less bound by convention, it has varied far more widely. Hence it is always easier to recognize a type-cutter from his italic than from his roman.

In England 'the sweet Roman hand' (*Twelfth Night*, III, iv, 31) only became popular with the cultured classes about the time of Elizabeth I. Half a century later, as England gradually acquired the carrying trade of the world, English commercial clerks developed a more rapid and rounded script, which became known abroad as *anglaise coulée*. The letters of Snell's commercial copybook of 1711 differ but little from those of Vere Foster on which the oldest of the present authors was brought up. The English type-cutters of the 18th century naturally modified the Franco-Dutch italic to conform with the national style. Baskerville, who was himself a writing master, and the later printers of 'modern' types, tended more and more to follow the flowing script of the copperplate engravers. During the 19th century, when italic ceased to be an independent type-face, one would have expected it to harmonize more closely with its roman context. Early attempts in this direction, as we have seen, were made by Fournier and others at the close of the 18th century; but in this country the principle has still secured only a half-hearted acceptance.

The motives which seem thus to have determined all these different styles are not unlike the reasons given by our readers to explain their own preferences. Those who prefer a scholarly and dignified hand admire the humanistic pattern of the older Italian type-cutters; those whose own handwriting tends to flourishes enjoy Baskerville with its swash capitals; those who look for a hand that is swift, practical and free from stylized mannerisms prefer the smooth and uniform roundness of Modern 7. Many of our teachers in particular stressed the fact that children often try to "write like a book", and produced several instances in which pupils suddenly altered their lettering on the introduction of a book with a novel type face. (A familiar instance is the occurrence of the Greek *e*, *d*, and even *a* in the handwriting of classical scholars.)

Among readers who took part in our experiments the sharpest clash of opinion arose between those who like their italic to contrast with the roman and those who think it should conform and harmonize. But here again much obviously depends on the reader's implicit notion of the functions of such a type—a point too frequently ignored. Is it to be used for prefaces, for passages quoted from ancient authors, for initial abstracts or summaries, for mathematical theorems, to provide an algebraic notation, to emphasize a conclusion or key phrase in the text, or merely for side-headings, stage-directions, and the like? For emphasis or headings many thought it more logical to use, not a cursive and therefore a lighter type, but heavy semi-bold roman. But all this raises yet another of the many problems awaiting psychological research. The layout of commercial advertisements has of late been rendered far more successful by the use of trial inquiries planned by a statistical

¹ In our preliminary experiments we also included 'Century'—one of the modern type-faces that has apparently achieved considerable popularity in America. It was rated quite highly by a small group of readers, who happened to be familiar with its use in a certain newspaper, but low by literary readers. The extremely short descenders and the large counters (notably in the *e*) no doubt are particularly suitable for newspaper work; but were criticised by many of our subjects, especially the teachers.

² A comparison with Petrarch's holograph does not bear out this pleasing tradition: see also Updike [5], I, p. 128.

³ See A. F. Johnson and S. Morison, 'The Chancery Types of Italy and France', *Fleurbaey*, III, 1924, pp. 23-52.

⁴ Now chiefly remembered for his Greek *New Testament* which remained the 'Received Text' for over three centuries. (At school I and my contemporaries studied the Greek Testament in a reprint subtitled "Textus Stephanicus, A.D. 1550". C.B.) In searching for an italic to accompany such faces as Bembo or Centaur, modern designs have usually reverted to the originals of Arrighi or Blado.

psychologist. Might not publishers benefit by similar preliminary investigations, instead of trusting to the conventional or impressionistic judgment of their production-manager or printer?

Mathematical Publications. The needs of a mathematical publication are somewhat specialized. The italic letters used as algebraic symbols seem to have become pretty well fixed during the 19th century when textbooks were for the most part printed in a 'modern' face. Hence many of our readers thought the *g*, *v*, *w*, *x*, and *y* as used in this journal "looked like an infringement of the customary symbols". The symbols suggested in *The Printing of Mathematics* are certainly superior; but even they are not wholly satisfying to the statistical psychologist. For example, the 'bold face series' there proposed (which the statistician would often need in matrix work) do not belong to the same type face nor do they correspond with the ordinary letters, as may be seen by comparing the *C*'s, *Q*'s, *v*'s, and *w*'s. Moreover, a statistical journal has additional problems of its own. Modern statistics requires Greek letters for the 'population' corresponding in slope and *x*-height to the roman letters used for the 'sample', and a variety of symbols far wider than that of the available alphabets. For these and other reasons Professor Kendall holds that there can be "no general standardization of symbolism, at any rate for some time to come". On the other hand, he agrees that there might be "a case for standardizing symbols in a particular branch" (26, p. 8). These, however, are questions that we hope to take up at a later stage in our inquiries.

A Note on the Psychology of History. In our paper (p. 44 above) we ventured to suggest that the history of typography might provide instructive illustrations of the broader psychological principles that underlie the course of history. Each of the great philosophers of the past has produced his particular 'philosophy of history': each has seen in it some kind of pattern, usually conforming with his special brand of metaphysics. The professional historian has, needless to say, usually scouted such generalized interpretations. Elsewhere, however, one of the present writers has argued that what is required is not a philosophy but a *psychology of history*, based on a direct analysis of empirical data. The historical study of typography would, we believe, admirably exemplify, in simple, concrete, and readily accessible form, most of the general principles that have been invoked to explain the larger course of events: the 'swing of the pendulum', the 'threefold dialectical movement' beloved of Hegel and Marx, the 'evolutionary pattern', the 'patternless pattern' ("just one dam' thing after another", as Professor H. A. L. Fisher maintained), and finally the economic, the technological, and the cultural patterns. The study of such trends is primarily a problem for the psychologist, a problem which, perhaps because of its complex nature, the psychologist himself has hitherto left severely alone. Nevertheless, it is our firm conviction that, by starting with the history of relatively simple forms of human activity, such as the various arts and crafts, to which typography forms an excellent introduction, an illuminating series of researches might well be undertaken, which would yield valuable data and instructive conclusions both for the historian and for the social psychologist.

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Note on Table of Type Faces. For the greater part of the nineteenth century printers had practically only one style of type at their disposal; today they can select a design from almost any period in the history of printing. The table opposite shows the most important of these faces, and is intended to illustrate the specimens chosen for our experiments and the criticisms made in the introspective comments.¹ To aid the reader in distinguishing the characteristics of the classes of type face indicated by the factorial analysis, we have included only those letters that vary widely from one fount to another; and, instead of following the usual alphabetical order, we have placed first those letters which have variants common to the largest number of families or groups. The nominal size is the same throughout, viz., 12 pt. In the text, where letters from different founts have been described or discussed, the exigencies of machine composition have forced us to set them in the type-face used for the rest of the article, namely, Times New Roman, *not* in the particular fount referred to.

¹ We regret that the printer has been unable to supply some of the type faces discussed in our article; the omissions relate chiefly to the less important founts, namely, Granjon, Didot, Centaur, and Gill Sans. Mr. H. W. Mortimer, a teacher who has been good enough to read the proofs, thinks that we should have included Gill Sans in our main experiments, "particularly when studying types for children's reading-books, for which it has achieved some popularity". However, as mentioned above (p. 32, footnote 2) our pilot inquiry indicated that, quite apart from their rarity as book faces, sans-serif designs by no means possess all the merits claimed for them. Here our conclusion is in keeping with that of H. R. Crosland and H. Johnson, who also found "serified letters more legible than unserified" (*J. Appl. Psychol.*, XII, 1928, p. 121). In the reading of *consecutive* print, as contrasted with the mere recognition of *isolated* letters, the serifs contribute appreciably towards the combination of the letters into a characteristic word-whole; as one type designer puts it, "they seem to aid the flow of the eye" (a phrase which is perhaps open to psychological criticism). In our experiments on numerals we certainly found Gill Sans better for *short* numbers (e.g., hours of trains, etc., as in railway time-tables, where they also facilitate economy of space); but they were less satisfactory for *long* numbers (as in mathematical tables), presumably because they do not combine so readily into distinctive groups. But we hope in the near future to publish a separate investigation on type for numerical publications, such as children's arithmetic books, tables in statistical papers and the like.

SPECIMENS OF TYPE FACES

IA1 Bembo	W M J Q R G c j g Th v w y z k p m g h J Q W
IA1 Centaur	W M J Q R G e j g h y v w y z k p m g h J Q W
IA1 Veronese	W M J Q R G N e j g z v w y z k p m g h J Q W
IA2 Garamond	W M J Q R G N e j g u n v w y z k p m g h J Q W A V R
IA2 Fournier	W M J Q R G Z A e b j g v w y z k p m g h J Q W
IA2 Plantin	W M J Q R G C A P e j g v w y z k p m g h J Q W
IA2 Ehrhardt	W M J Q R G C A E T U j g c b p q f r v w y i j k p m g f J Q W R P B D
IB Caslon	W M J Q R G C A H U e v w y z k p m g J Q W C Y A V H
IB Baskerville	W M J Q R G C A H e w g s v w y z k p m g J Q W C Y K N T
IB Old Style	W M J Q R G C A H e w g s v w y z k p m g J Q W C Y
IB Imprint	W M J Q R G C A e w g s v w y z k p m g J Q W C Y
IB Times New Roman	W M J Q R G C e w g s c b p q v w y z i j k p m h J Q W
IB Perpetua	W M J Q R G C A E T U j g c b p q f r v w y i j k p m g f J Q W R P B D
IIA Bodoni	W M J Q R G C K e w j b t u n v w y i j k p m t x g J Q W R
IIA Walbaum	W M J Q R K e w g j b t v w y i j k p m t x J Q W R
IIB Bell	W M J Q R K e w j b t k v w y i j k p m t x g J Q W
IIB Scotch	W M J Q R K e w j b t k v w y i j k p m t x g J Q W R
IIB Modern 7	W M J Q R K U e w j b t h v w y i j k p m t x g J Q W R

INTERNATIONAL CONFERENCE ON FACTOR ANALYSIS

The *Centre National de la Recherche Scientifique*, aided by a generous grant from the Rockefeller Foundation, is organizing a *Colloque International* on 'Factor Analysis and its Applications', to be held in Paris from 11th to 16th July, 1955. The provisional programme is as follows:

11TH JULY. Inaugural addresses and report on the Uppsala symposium.

Professor L. L. Thurstone, 'Recent studies in factor analysis'.

Professor Sir Cyril Burt, 'Factor analysis: historical survey of methods and results'.

Professor H. Piéron, 'Le problème général de la recherche et de la nature des facteurs en psychophysiologie'.

12TH JULY. *Professor H. Hotelling*, 'Relations of the newer multivariate statistical methods to factor analysis'.

Professor H. Pineau, 'Remarques sur l'analyse factorielle de Hotelling et comparaison avec les méthodes centroïdes'.

Professor M. Yela, 'Résultats et signification psychologique de l'analyse factorielle'.

Mme. G. Bernyer, 'Les facteurs psychologiques: leur nombre, leur identification, leur nature'.

Professor M. Reuchlin, 'Facteurs obliques, facteurs orthogonaux, facteurs de second ordre, en psychologie'.

13TH JULY. *Dr. L. Guttman*, 'The Radex approach to factor analysis'.

M. J. M. Faverge, 'Analyse factorielle et combinaisons linéaires de variables'.

Dr. H. J. Eysenck, 'The validity of factor analysis'.

M. E. Schreider, 'Application de l'analyse factorielle à l'étude de la variabilité biologique'.

Dr. S. Leder mann, 'Application de l'analyse factorielle à l'étude de la mortalité'.

15TH JULY. *Professor G. Darmon*, 'Quelques résultats théoriques et leurs conséquences pour les applications'.

Professor P. Delaporte, 'Nouvelle méthode de statistique mathématique pour l'estimation des facteurs'.

Dr. A. H. El Koussy, 'Trends of research in space abilities'.

Professor T. Husen, 'Factor analysis of achievement tests'.

Professor E. A. Peel, 'The factor analysis of correlations between persons with independent determiners to identify factors'.

16TH JULY. *Sir Cyril Burt*, Summary of Conference. Final Discussion.

BOOK REVIEW

Faster than Thought: A Symposium on Digital Computing Machines. Edited by B. V. BOWDEN
London: Pitman & Sons. Pp. xx + 416.

MUCH of the calculation required in statistical psychology will in the near future be performed by electronic computers. Hitherto, psychologists who have devised working techniques for factor analysis and similar procedures have striven to keep them as simple as possible: usually they have had in mind a student or research worker equipped with only a hand machine or with nothing at all. This preference for easy methods—for graphical rotation instead of arithmetical rotation, simple summation instead of weighted summation, guessed communalities instead of correcting for specificity or applying maximum likelihood—has frequently provoked the criticisms of the professional mathematician, and is now gravely impeding the development of rigorous and efficient formulae. The time has therefore arrived for the psychologist to adapt his working methods to the improved facilities now available; and with that end in view he should familiarize himself with the nature and capabilities of these novel appliances. As an introduction to the subject the volume that Dr. Bowden has edited is at once the most up-to-date, the most readable, and the most authoritative.

Dr. Bowden begins by reminding us how, in every civilized country, the organization of industry and government is growing more and more complex. "The welfare state", he warns us, "can only be run efficiently on a diet of numbers; and as a result we seem to be fast becoming a nation of computing clerks." But the 'electronic brain' is "now waiting to come to the rescue". Not only can it calculate with astonishing speed; it can store, recall, and reorganize data far more accurately and promptly than a whole army of clerks. Unfortunately in Britain (so at least we are told) the social psychologists, the industrial psychologists, and those who advise on 'scientific management' have hitherto shown little sign of appreciating what can be accomplished by such means.¹ If Dr. Bowden's hopes are realized, this generation will soon be witnessing a second industrial revolution: in the first, the machine replaced men's muscles, so that every English workman now has on an average three horse-power to help him; in the next, it will largely replace his brain, and incidentally lighten the drudgery and boredom that now oppresses the white collar worker.

The book, which is profusely illustrated, falls into three main parts. The first deals with the history and theory of mechanized computation; the second with the commoner types of machine that have recently been built; and the third and longest with the more important fields of application.

The opening chapter, written in Dr. Bowden's liveliest style, presents a brief historical survey of calculating devices from the days when Sumerians stamped their accounts on clay tablets. To the psychologist the spasmodic way in which the whole project has developed is itself a problem of singular interest. The first effective adding machine was built by Blaise Pascal in 1642 at the age of 19, to assist his father, who was an officer of the French customs: it can still be seen in the *Conservatoire des Arts et Métiers*. Thirty years later, Leibniz exhibited before the Royal Society of London an invention of his own which could not only add but multiply. Nevertheless, two hundred years later the tables in the *Nautical Almanac* were still being calculated by officials at the Greenwich Observatory, and contained so many inaccuracies that few experienced navigators would use them.² However, shortly after the beginning of the nineteenth century, it occurred to a young Cambridge mathematician that fatal errors of this kind could be avoided if all tabular functions could be computed by machinery; and, although during his lifetime nothing practical emerged from his prolonged investigations, it is now quite obvious that he had successfully hammered out all the basic principles on which modern digital computers are built.

Charles Babbage was the son of a banker, and thus a man of means. Though he had left Cambridge without sitting for the Tripos, he became a Fellow of the Royal Society at 22, and at 36 was elected to the Lucasian Professorship of Mathematics, the Chair once held by Newton. This office he retained from 1829 to 1839 without giving a single lecture. Babbage was a highly original inventor. He is said to have devised the cow-catcher, the first speedometer, 'skeleton keys for unpickable locks', ingenious dodges for solving codes and ciphers, a valuable method of detecting

¹ Quite recently J. Lyons & Co. have installed 'Leo', an electronic office which works out the weekly wage-packets of their 7,000 London employees, analyses day by day the trend of orders in the various teasops, and is rented in its spare time to outside bodies. To cover developments in automatic control, a vice-president of the Ford Motor Company has coined the word 'automation' (cf. R. K. Geiser, *Conference on Automation and Industrial Development*, New York, May, 1954). In this country the Joint Committee on Human Relations in Industry, set up by the Department of Scientific and Industrial Research and the Medical Research Council has sponsored a small pilot research at Cambridge on automatic control in industry; and, while these pages are going through the press, P.E.P. has issued an instructive pamphlet on the subject ('Towards an Automatic Factory', *Planning*, XXI, 1955, pp. 64-84).

² We are told that Captain Smyth, R.N., while making a survey of the Mediterranean, fell in with a Spanish vessel, and, during the exchange of courtesies, presented the navigator with a handsomely bound copy of the *Almanac*. Captain Smyth who "sailed by rule-of-thumb", returned to Portsmouth quite safely: the Spaniard was never heard of again.

climatic cycles based on rings of tree-trunks, and finally the occulting lighthouse. His analysis of post office economics led to Rowland Hill's introduction of the penny post; and he even anticipated the experiments of Professor J. B. S. Haldane by spending ten minutes in an oven at a temperature of 265° Fahrenheit.

To cut the cogs for his computing machines with sufficient regularity, great improvements had to be made in lathes and precision-tools; and in workshop methods alone his achievements, as Dr. Bowden remarks, must have more than justified the grant which the Government gave him towards constructing his earlier models. To feed in the figures for his computing mechanisms to work with, he hit upon the idea of using the punched cards that had just been invented by a French weaver, Joseph Jacquard, for controlling his looms.¹ Unhappily, and not always through faults of his own, hardly any of the machines that Babbage designed and started were actually completed; dexterous as he was in handling tools and formulae, he had no flair for explaining his ideas to others and was wholly devoid of the tact and good temper needed to cope with government officials and scientific critics. He died, a disappointed visionary, in 1872; and his workshops were found littered with what a contemporary described as "the wreckage of a brilliant career, and bits of machine which will doubtless remain for ever a mere theoretic possibility".

In his own eyes his greatest feat was the invention of a new algebra to describe the logical relations between the various parts of his machinery. The symbolism proposed was highly ingenious. But Babbage himself was too engrossed in applying his principles to publish any clear or comprehensive exposition of them. The best account both of his methods and of his machines we owe to another extraordinary personality, Ada Augusta, Countess of Lovelace.

Early in 1815, Lord Byron married "a young heiress and savante" named Miss Milbanke. In his love letters he calls her his "Princess of Parallelograms". In *Don Juan*² she figures as "the winsome Donna Inez, Don José's learned wife", "Her favourite science was the mathematical." A year later "Don José and his lady quarrelled", and "were for ever parted". Meanwhile a child had been born—

Ada, sole daughter of my house and heart,
A child of bitterness, though born in love.³

"My voice", he says elsewhere, "shall with thy future visions blend, To aid thy mind's development." And indeed her mind apparently inherited both her father's literary talents and her mother's mathematical abilities. As a girl she studied under Augustus de Morgan, Professor of Mathematics at University College, London. One day his wife took her to see "Mr. Babbage's engine". "While the rest of the party" (says Mrs. De Morgan) "gazed at the instrument with the expression savages are said to wear on first seeing a clock or a gun, Miss Byron, young as she was, saw the great beauty of the invention and understood its working."⁴ A few years later she married William King, afterwards first Earl of Lovelace. She and Babbage remained close friends; and of all his contemporaries she alone seems to have really grasped what he was trying to do.

In 1840, Babbage gave a series of lectures at Turin. They were attended by L. F. Menabrea (an officer of the Italian Military Engineers and in later years one of Garibaldi's generals) who wrote out a detailed 'Sketch of the Analytical Engine invented by C. Babbage'. Lady Lovelace translated his paper into English, supplementing the description with valuable mathematical notes and first-hand explanations, and drawing up an intricate chart or 'programme' for computing the Bernoulli numbers by way of illustration. Later she and Babbage worked out an elaborate mathematical system of betting on horses, and endeavoured by its means to raise funds to build a still better machine. Both lost heavily. Shortly afterwards, at the early age of 37, she died, and was buried beside her father at Newstead Abbey. Dr. Bowden has had the happy idea of reprinting the whole of her memoir in an Appendix of sixty pages.⁵

¹ A few years after Babbage's death the same idea occurred to Dr. Hollerith, then in charge of the American Bureau of the Census. Although by law a U.S. census had to be taken every ten years, the work had grown so rapidly that with existing methods it would have taken twenty years to complete the requisite calculations. Hence the 'Hollerith sorter' with which every psychologist is nowadays familiar.

² The story is told in the first thirty cantos, as an awful warning to any who would "wed a walking multiplication table", with the final moral:

Oh, lords of ladies intellectual,
Inform us truly, have they not henpeck'd you all?

The footnotes to Murray's edition of 1837 explain the rather cryptic allusions. See also 'Fare Thee Well, March, 1816', the manuscript of which, says Murray, "is blotted all over with the marks of tears".

³ *Childe Harold's Pilgrimage*, III, i, cxviii. It is curious that no editor, commenting on the poet's repeated speculations about the "destiny of his only child", ever tells the reader what her destiny actually was.

⁴ See this *Journal*, IV, 1951, pp. 198 f. As Dr. Bowden remarks, "the attitude of the average intelligent man towards mathematical devices has changed very little during the last hundred years".

⁵ Babbage himself considered Lady Lovelace's account of his machine to be the best available, and noted that she had corrected an error in his own recurrent formula for computing the Bernoulli numbers.

A passion for mathematics, horse-racing, and foreign adventure appears to have run through her family for two or three generations. Her daughter, a brilliant mathematician and Arabic scholar, married Wilfred Scawen Blunt, the poet, and sought to introduce Arab blood into the race horse (see *The Authentic Arabian Horse*, 1942, by Baroness Wentworth, her granddaughter). When in a broadcast talk I mentioned Lady Lovelace and her mother and daughter as members of a remarkable mathematical family overlooked by Galton, I received a letter from another of her descendants telling me that several living members were equally gifted, and that one happened to be working for a well-known manufacturer of computing machines.

The subsequent history of computing machines from the days of Babbage to those of the earliest electronic computers is dismissed rather briefly¹; and the remainder of Part I consists in a comprehensive and lucid account of the internal organization of the modern high speed instrument and of the circuit components and other mechanisms on which its working depends.

Part II is devoted to the description of existing machines. Nearly a dozen different specialists contribute a chapter each on the latest types now working in this country and in the United States. The British psychologist in particular will be grateful for the full details about the construction and capabilities of the machines available at Birkbeck College, Imperial College, and the National Physical Laboratory.

The third and longest part of the book is concerned with the applications of such machines. It discusses at some length the services which they have rendered, or might render, in government offices, in business and commerce, in the fighting services, in crystallography, meteorology, dynamical astronomy, and in various branches of scientific engineering. To the psychologist the chapter of greatest interest will be that dealing with the solution of logical problems.

Once again the history of the basic idea goes back to Leibniz; in a well-known passage, he declared that, with the methods that he advocated, "wrangling would be as unnecessary between philosophers as it is between accountants: they would simply say: 'Let us calculate'". To take his own example, suppose 'man' to be represented by the number 6; then the prime factors of this number may represent 'rational' and 'animal': thus the proposition 'man is a rational animal' will be represented by analysing 6 into its factors, 2 and 3. And, with more complex subjects, an *ars combinatoria* will enable us to construct and compare all the relevant combinations of such factors.² In this way logic will become a kind of algebra.

What Leibniz only dreamt of, George Boole actually carried out. In 1848, Boole (professor of Mathematics at Queen's College, Cork) published his *Mathematical Analysis of Logic*, which was later expanded into his more celebrated *Laws of Thought*—a book that Bertrand Russell once hailed as the most momentous contribution to formal logic ever written. Its object was "to express the operations of reasoning in the language of a calculus". From this it was a comparatively simple step to invent an apparatus that would apply the calculus. The first machine to be actually constructed was the 'logical piano' designed by Stanley Jevons (another of De Morgan's students at University College and later Professor of Political Economy there): a woodcut of it forms the frontispiece to his book on *The Principles of Science*.³ The instrument, as he tells us, was inspired by the work of De Morgan and Boole. Its operation assumes the logic of dichotomous classification (X and not-X, etc.); and the essential processes have an instructive analogy with the factorial analysis and factorial synthesis of qualitative data.

The statistical psychologist often finds it difficult to persuade his critics that the algebraic methods that he adopts are merely an application of rigorous logical principles: perhaps a more effective line of explanation would be achieved if he argued in the opposite direction, and tried to show, as Jevons does, that complex logical problems, starting with purely qualitative data, can be efficiently solved by the application of mathematical formulae. Let us therefore begin by comparing the procedure proposed by Jevons with that adopted by the statistical psychologist.⁴ This will help us to a clearer understanding of the principles embodied in the more modern logical machines described by Dr. Bowden.

The logical reasoning which Jevons' machine is capable of performing is based on the principle that all purely logical relations may be expressed in terms of (1) conjunction and (2) negation: thus, 'Either A or B' may be expressed by saying 'The conjunction of Not-A and Not-B does not occur'; 'If A, then B' by saying 'the conjunction A and Not-B does not occur'; and so on (Jevons, *loc. cit.*, pp. 73 f.). And from this it would evidently follow that every statement, so far as it involves logical relations, can be expanded in a *logical sum of logical products* (the so-called 'Boolean expansion'). Such an expansion can be computed by methods akin to matrix multiplication, which consists essentially in forming product-sums. However, instead of the somewhat abstruse examples borrowed

¹ For this intervening period the reader may refer to David Baxandall's excellent article on 'Calculating Machines' in the *Encyclopaedia Britannica* (14th edn., 1929). A machine which fully exploited the principles set forth by Babbage was not actually built until a hundred years after he had formulated them. This was the sequence-controlled calculator, known as Harvard Mark I, designed by Professor Aiken of Harvard in 1939 and put into service a few years later; its calculating elements consist of mechanical counters driven through electro-magnetic clutches which in turn are controlled by electromechanical relay circuits. The first all-electronic computer was the Electronic Numerical Integrator and Calculator (ENIAC) built at the School of Engineering, University of Pennsylvania, 1946; it contained 18,000 valves and 1,500 relays, and works several hundred times faster than the Harvard Mark I. Still more ingenious models have since been designed by Professor von Neumann and his co-workers at Philadelphia, and affectionately christened EDVAC, EDSAC, JOHNIAC, and MANIAC.

² Leibniz's proposals are contained in a rather rare tract, entitled 'Non inelegans Specimen Demonstrandi in Abstractis' (Erdmann, *Leibniz Opera*, 1840, I, pp. 94 f.). The most instructive passages are quoted by Jevons in the Preface to the second edition of his *Principles of Science* (1877).

The 'frame or engine' with forty iron handles "for improving speculative knowledge by mechanical operations", which the professor demonstrated to Gulliver at the 'grand academy of Lagado', was presumably suggested to Swift by Leibniz's demonstrations to the Royal Society: Sir Walter Scott, however, supposed it to be based on Ramón Lull's *Arx Magna*.

³ W. S. Jevons, *Phil. Trans.*, CLX, 1870, pp. 497 f.; *id.*, *The Principles of Science*, 1874, pp. 108 f.

⁴ Cf. 'The Factorial Analysis of Qualitative Data', this *Journal*, III, 1950, pp. 166-185.

by Jevons from physics or chemistry, let us start with a concrete problem so simple that its solution is obvious almost at once.¹

Just before the war, a local education authority gave the following instructions to a recently appointed psychologist. "Pupils who are innately deficient in general intelligence or are backward in the essential subjects of the elementary curriculum by three or more years are regarded as educationally subnormal. All other pupils will be regarded as normal and will attend the ordinary elementary school. Pupils who are subnormal must be recommended for transference to the special school. The term 'pupil' here includes any boy or girl between the ages of 5 and 14 who is physically fit for classroom instruction." The psychologist thereupon asked himself: "how precisely do I classify the children referred to me, and which of these classes am I to recommend as fit for a special school or for an elementary school respectively?"

Confronted with a problem such as this, we start, as Leibniz and Jevons would have us do, by expressing the relevant qualifications in terms of four components or 'factors': (i) *G*, a positive or 'general' factor, denoting the whole universe or *genus* of 'pupils'; (ii) *X*, a first 'bipolar', denoting suitability for a 'special school' or the reverse; (iii) *A*, another bipolar, specifying presence or absence of innate 'deficiency'; (iv) *B*, a third bipolar, specifying presence or absence of 'educational backwardness'. Thus, in theory, the entire *genus* will consist of $2^3 = 8$ conceivable classes of persons which we can number from i to viii.

We now require symbols to indicate the positive or negative aspects of these components. With literal symbols, we can use (with Jevons) *X* and *x*, or (with Woodger and others) *X* and $-X$, or (with Welton) *X* and $\bar{X}$. With numerical symbols we can enter in the row or column reserved for the component in question either (+1 for the positive term) and -1 (for the negative term) or again (b) 1 (for presence) and 0 (for absence). It will be seen that these numerical alternatives correspond with the factorist's choice between a bipolar factor and a group factor. In the electronic machine the alternatives may similarly be represented in two different ways. (a) They may be indicated by a pair of contrasting signals, the mere absence of a signal conveying no information: this is the principle adopted in the old Morse code machines and in the machine built by the Telecommunications Research Establishment at Malvern. Or (b) they can be represented by a relay or a switch which is either 'on' or 'off': this is the device now adopted by most electronic machines.

In my previous paper I used the second type of notation (0 or 1). Here I shall attempt to show how the first can be used. Adopting this convention we can specify the 8 classes by a 'bipolar' matrix, such as the following:

Classes of Persons		i	ii	iii	iv	v	vi	vii	viii
Factor	<i>G</i>	+1	+1	+1	+1	+1	+1	+1	+1
"	<i>X</i>	+1	+1	+1	+1	-1	-1	-1	-1
"	<i>A</i>	+1	+1	-1	-1	+1	+1	-1	-1
"	<i>B</i>	+1	-1	+1	-1	+1	-1	+1	-1

With the alternative notation we should obtain a matrix in terms, not of 'bipolar factors', but of 'group factors'. But the bipolar matrix can evidently be rotated to the group factor form by means of the following pre-multiplier:

		Bipolar Factors			
		<i>G</i>	<i>X</i>	<i>A</i>	<i>B</i>
Group Factors	$\left\{ \begin{array}{l} G' \\ X' \\ A' \\ B' \end{array} \right.$	1	0	0	0
		$\frac{1}{2}$	$\frac{1}{2}$	0	0
		$\frac{1}{2}$	0	$\frac{1}{2}$	0
		$\frac{1}{2}$	0	0	$\frac{1}{2}$

Out of the eight conceivable classes deducible from these three 'bipolar factors' the regulations regarding special schools exclude a certain number by imposing the requirement $X = A \vee B$ (i.e., that *X* must be either *A* or *B*). The next step, therefore, is to determine what classes are covered by the requirement 'either *A* or *B*'. The requisite operation can be carried out by first rotating the bipolar matrix as above described, and then applying the summation premultiplier $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$ to obtain

the 'logical sum' of the two lower rows resulting from the rotation, namely *A'* and *B'*. The type of summation required will follow the usual rules, except² that $(+1) + (+1) = +1$: (the procedure is in some ways analogous to 'unweighted summation' in factor analysis). The premultiplier $\begin{bmatrix} -1 & 2 & 0 \\ -1 & 0 & 2 \end{bmatrix}$ will then convert the three one-or-zero rows back to bipolar form, thus yielding two bipolar rows.

¹ It should be noted that 'or' is taken in a non-exclusive sense: as Mill puts it, "when we say *X* is 'either a knave or a fool' we by no means imply that he cannot be both". Thus our 'group factors' may overlap. Dr. Bowden's example therefore seems unfortunate, since it tacitly rules out the *joint* possibility, whereas his machine obviously does not.

² The apparent paradox has a perfectly logical explanation: +1 in the new row *A* and cols. i, ii, and iii means "all in classes i, ii, and iii are *A*"; +1 in the new row *B* means "all in subclass i are *B*". The logical sum states 'all in classes i, ii, and iii are either *A* or *B*' (in the non-exclusive sense). And in each case we must again use '+1' to denote 'all'.

For the last step we note that the relation of equivalence is expressed by the operator [$\frac{1}{2}$, $\frac{1}{2}$]. On using it to pre-multiply the two bipolar rows just obtained, we get a single row, whose values contain the solution to our problem, namely:

Subclass	i	ii	iii	iv	v	vi	vii	viii
Final result	1	1	1	0	0	0	0	-1

These results indicate that, with the requirements imposed, only the first three classes, $GX(AB)$, $GX(\overline{AB})$, $GX(\overline{A}\overline{B})$, and the last, $G\overline{X}(AB)$, satisfy the regulations: the former, as we see, specify those persons that are fit for a special school (X), the latter, those that are not ($\overline{X}$). The four remaining classes (those marked zero) are forbidden by the regulations, either explicitly or implicitly.

In practice most readers would doubtless solve an elementary problem like this almost intuitively, without recourse to symbols and conscious inference.¹ But with the blind working of an artificial apparatus a step-by-step routine is unavoidable. To demonstrate the possibility of such an instrument, Ferranti, Ltd., have built an electronic contrivance capable of dealing with three components: at Harvard a larger machine will deal with as many as twelve.²

With the method I have described, it will be seen, the last step of all involves scanning the final results for each possible combination. Three components yield only 8 combinations; but 12 would yield as many as 4,096; and twenty over a million. Thus the number to be scanned rises swiftly to an amount that is quite impracticable even for the most up-to-date high-speed appliances. Fortunately, when the problem is of great complexity, it is often sufficient to obtain just one positive solution, without discovering all. In that case an alternative principle may be exploited—that of feed-back. Constructed in this fashion the machine can work 50,000 times faster; and its behaviour is virtually that of what is known as a discrete Markoff process.³ Once again Ferranti, Ltd. have designed a machine based on this principle, which is also capable of furnishing *every* solution, when the problem is of a comparatively simple type.

Most of the logical problems handled by such appliances are, like the example I have used, problems to be solved by deduction: the data of the problem offer us the relevant classificatory components or 'factors' ready to hand. But in the natural sciences such classifications have to be discovered first of all. In psychology, this preliminary inductive stage constitutes one of the special tasks of factorial research—that of factor analysis as distinct from factor synthesis. It is to be hoped, therefore, that in the near future both designers and programmers will devote attention to these more exacting demands.⁴

The machines that seem chiefly to have hit the popular imagination are those that play games. As long ago as 1769, Baron Kempelen exhibited a chess-playing automaton which was able to defeat the Emperor Napoleon. It was described in some detail by Edgar Allan Poe; but, according to the story, the hoax was unmasked when somebody shouted 'Fire', and the legless dwarf concealed inside struggled frantically to escape. Babbage designed an apparatus which could play 'noughts and crosses'. And many readers may have tried to beat the machine called 'Nimrod' at the game of Nim, when it was installed at the Science Museum during the Festival of Britain. Dr. Bowden describes computers that will play both chess and draughts, the former rather badly, the latter quite well.

Encouraged by these remarkable feats of scientific engineering, physiologists, psychiatrists, psychologists, and philosophers (chiefly psychologists who are behaviourists and philosophers who are logical positivists of the physicalistic persuasion) have recently proclaimed that we are now wholly justified in regarding the human mind as no more than a highly developed physical machine. Henceforth we may confidently dispense with what Professor Ryle has dubbed 'the ghost within the machine'. Allowance must of course be made for differences in complexity: while the most elaborate computer contains no more than 5,000 valves, the average brain includes over 10,000,000,000 nerve cells (about six times the population of the globe). That being so, it is argued, we may safely attribute the obvious disparities between the two to the inequality in initial equipment. In short, "mind and mechanism differ only in degree and not in kind"—a conclusion which raises the perplexing questions discussed by Dr. Bowden in the closing chapter of his book.

He begins by comparing the actual performances of the most efficient machines with those of the most efficient human computers, and presents a highly instructive survey of the accomplishments

¹ The reader who finds the foregoing excessively simple may try one of those cited by Jevons, which contains the same number of components: "According to the prospectus members of the public could subscribe to the company by purchasing bonds, shares, or both. The directors are all bond-holders or share-holders but not both; and all the bond-holders are directors. What conclusion can be drawn?" We are told that, of 150 students, only 6 gave the answer. It may be noted that Jevons' instrument is capable of inductive as well as deductive inference.

² Cf. W. Mays and D. G. Prinz, 'A Relay Machine for the Demonstration of Symbol Logic', *Nature*, CLXV, 1950, Feb. 4.

³ See this *Journal*, IV, 1951, p. 194.

⁴ Using the method of principal components, Dr. Wrigley and Dr. Neuhaus have factorized a 7×7 correlation matrix in about 10 minutes' machine time ('A Refactorization of the Burt-Pearson Matrix with the Ordvac Computer', this *Journal*, V, 1952, pp. 105-108). But no one as yet has attempted solutions that depend on 'correction for specificity', 'simple summation', 'group factor analysis', or the use of 'subdivided factors'. To illustrate the unexpected difficulties of statistical work, Dr. Bowden prints a chart for 'part of a multiple regression (*sic*) analysis', but does not enter into detailed explanations.

and methods of Professor A. C. Aitken, F.R.S., and Mr. William Klein, of the Mathematisch Centrum, Amsterdam. On the whole, it would seem, the machine has the advantage as regards complexity of problem, memory for figures, and speed of solution. These happen to be the features in which 'calculating prodigies' themselves outdistance the ordinary man. On the other hand, the human expert possesses at least two advantages over the machine: first, he can choose or adapt his method according to the accidental peculiarities of each problem, and thus improvise short cuts in a way that is quite beyond the scope of any machine; secondly, he is endowed with a power of 'schematic apprehension', which no one has yet succeeded in imparting to an instrument: whereas the human calculator can grasp and manipulate whole patterns or *Gestalten*, the machine is compelled to work explicitly step by step.¹ *Prima facie* this suggests a difference of quality rather than of mere complexity or degree.

To examine the pros and cons of this ancient controversy would take us too far afield.² But it is worth while hearing the verdict of the engineers. As Dr. Bowden's quotations show, most of them are inclined to deprecate "the attempt to infer complete similarity from partial similarity, however striking". He himself points out that, although the engineers can produce a mechanized Barlow (who computed tables of squares and powers), and a mechanized Briggs (who compiled tables of logarithms), they have not even hinted at the possible production of a mechanized Napier (who *invented* logarithms). And at least one impartial critic, speaking as a philosopher as well as a psychologist, emphatically agrees. "There was once", says Professor Mace, "a monk who invented a machine which could prove the existence of God. The monk, however, was cleverer than the machine: for, up to the present, no machine has invented a monk who could prove anything at all."³ Perhaps we may allow Lady Lovelace to have the last word (the italics are her own). "The analytical engine has no pretensions to *originate* anything; it can *merely do what we order it to perform*."

CYRIL BURT.

¹ Professor Aitken, in the course of a broadcast in which Dr. Bowden and I were allowed to question him, remarked that the process seems to imply "a compound faculty, which, so far as I am aware, has never been exactly described". He suggests that "the analogy of the musician might help: a violinist concentrates, when he is playing, on the tune as a whole not on the separate notes or the fingering—except when he gets momentarily into a tangle".

² I have discussed the question in greater detail at the close of a recent paper in *Brit. J. Educ. Psychol.*, XXV, 1955, pp. 18 f.

³ Preface to W. Sluckin's *Minds and Machines* (Penguin Books, 1954), p. 9. The reference is, I take it, to the earliest recorded logical machine, the *Ars Magna* (c. 1300) of Ramón Lull (a Spanish missionary and mystic who hoped that his proofs would convert the Moslems, but he was stoned to death by them at the age of 80). Francis Bacon, however, pronounced that it was a *methodus imposturae*.